SCIENCE a modern approach

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SCIENCE CONSULTANTS

Owen Chamberlain, A.B., Ph.D.
Professor of Physics
University of California
Berkeley, California

Robert C. Stebbins, A.B., M.A., Ph.D.
Professor of Zoology
University of California
Berkeley, California

MATHEMATICS CONSULTANT

Leonard Simon, B.S., M.A.
Acting Assistant Director
Bureau of Curriculum Research
New York, New York

READING CONSULTANT

Theodore E. Glim, A.B., M.A., Ed.D., Ph.D.
Assistant Superintendent of Instruction
Shoreline Schools
Seattle, Washington

CURRICULUM CONSULTANT

Alexander Pepe, B.A., M.A.
Elementary Science Teacher
East Side School
Cold Spring Harbor, New York

SCIENCE MATERIALS CONSULTANT

Nick Oddo, B.A., M.A.
Elementary Science Cooperative Support Teaching Project
Berkeley Unified School District
Berkeley, California

Holt, Rinehart and Winston, Inc., New York

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Abraham S. Fischler

Lawrence F. Lowery

Sam S. Blanc

AUTHORS

Abraham S. Fischler
Professor of Science Education
University of California
Berkeley, California

Lawrence F. Lowery
Teacher-Principal
Oakland Unified School District
Oakland, California

Sam S. Blanc
Director of Science and Mathematics
Cajon Valley School District
El Cajon, California

Contributing authors

Peter Dean

Mario DiGesu

Albert Carr

Illustrated by

Jerry Lazare
Michael Lowenbein
Bill McKibbin
Jo Polseno
Harry Schaare
Jim Walker

Cover design by Aaron Heller

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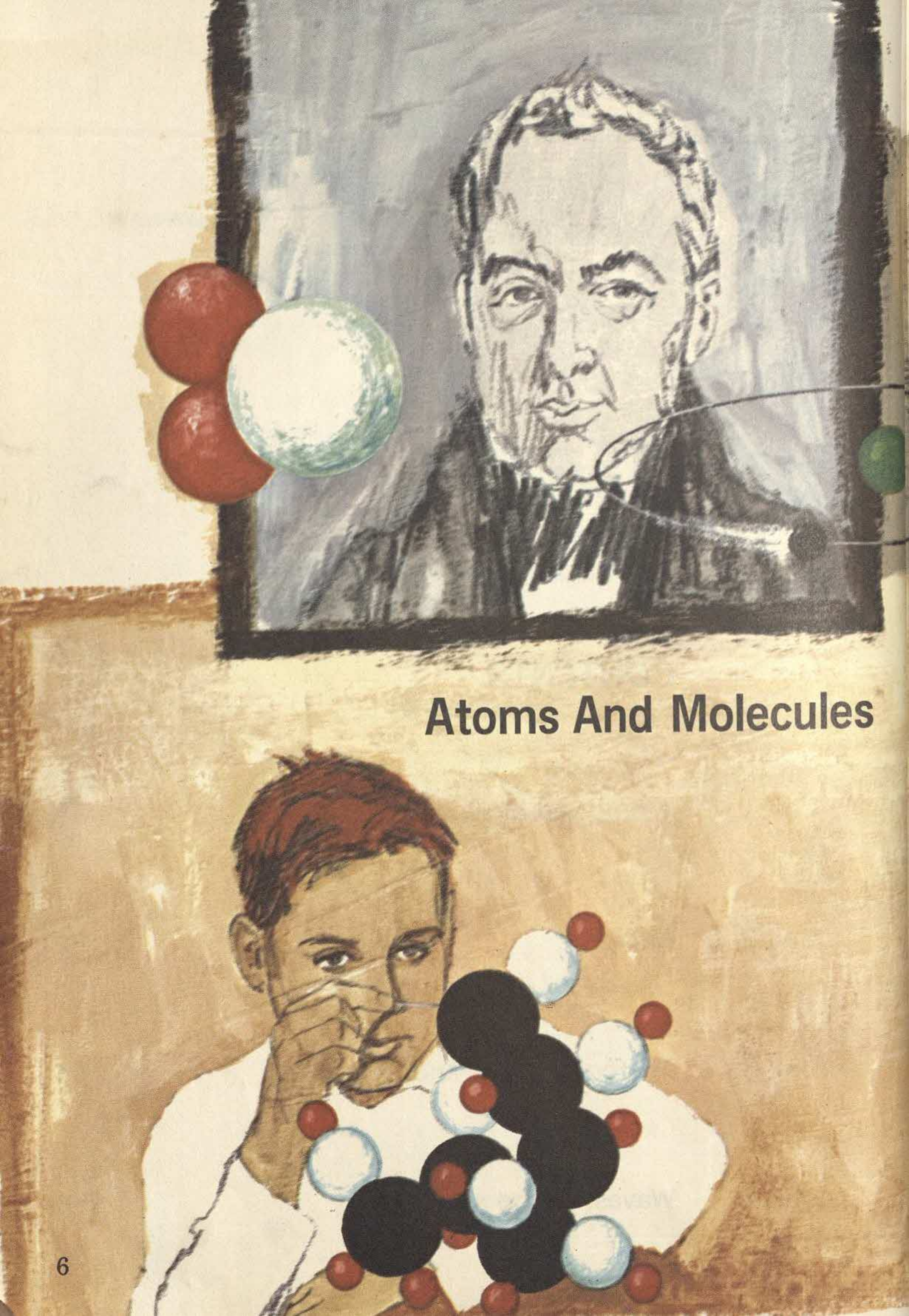
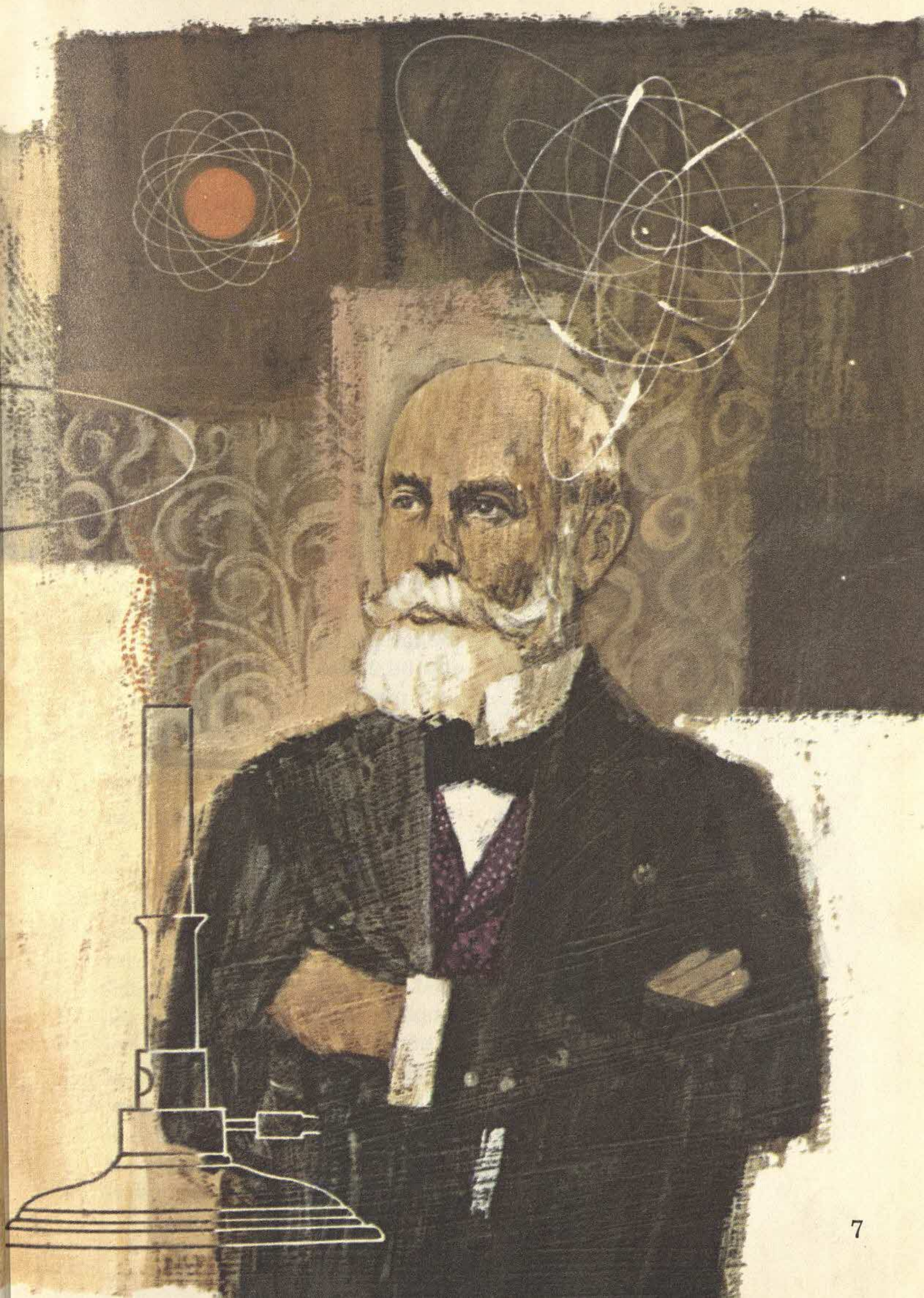


Atoms And Molecules



What Are Things Made Of?

Have you ever heard or read that we live in an atomic age? By this time it is almost certain that you have heard such expressions as "atomic bomb" or "atoms for peace." Through newspapers, magazines, radio, and television you have most probably encountered the word, atom, hundreds of times.

Do you ever wonder about atoms? Have you ever wondered what they are or where they come from? You may have read or heard that they are invisible particles and, if you are like most people, you know that atoms are not easy to understand without careful study and a great deal of experimentation.

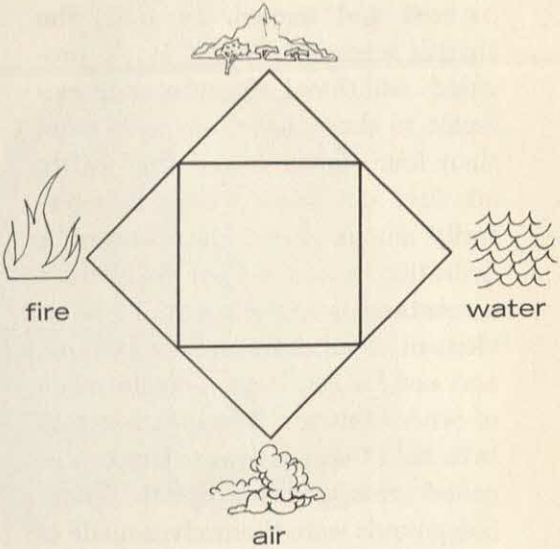
Have you ever asked yourself whether or not atoms really exist? What are atoms? Where are they found?

It may surprise you to discover that you already know more about atoms than the wisest thinkers from ancient times. It is true that they did not know too much about the atoms we learn about today, but how important and clever it was to give the idea a beginning. Even more clever was the question that gave rise to the idea of atoms. Someone, a person whose name we may never know, long long ago thought of asking the question, "What are things made of?" The question is at least 3,000 years old. We know about this question from the religious songs of the early Hindu people who lived in about 1,200 B.C. They believed that the material "touchable" world, which today we call matter, was made of tiny pieces with spaces between them. If anyone had this idea before the ancient Hindus, we do not as yet know about it.

Early Ideas About Atoms

The ancient civilization of Greece had more than a normal share of great thinkers. Some of these philosophers were also interested in the question, "What is the world made of?" Several Greek thinkers believed in the teachings of Empedocles (em-PED-oh-klees), who taught that all of the substances on earth were made from four *elements:* earth, air, fire,

Empedocles



and water. They also believed that a fifth element, which they called ether, made up the heavens.

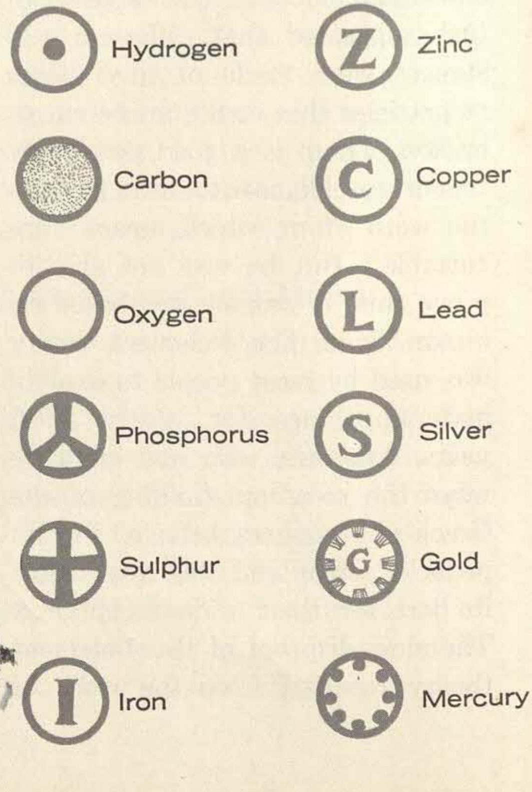
About 450 B.C. a philosopher named Democritus (deh-MAHK-rih-tus) suggested that different substances were made of tiny pieces or particles that could not be cut or broken. There is a good possibility that it was Democritus who gave us the word atom, which means "uncuttable." But he was not able to prove this; it was an idea based on reason alone. The 4-element theory was used by most people to explain material things for nearly 2,000 years. Aristotle, who was in many ways the most outstanding of the Greek philosophers, believed in Empedocles' ideas and was responsible in part for their wide acceptance. The slow disproof of the 4-element theory resulted from the work of

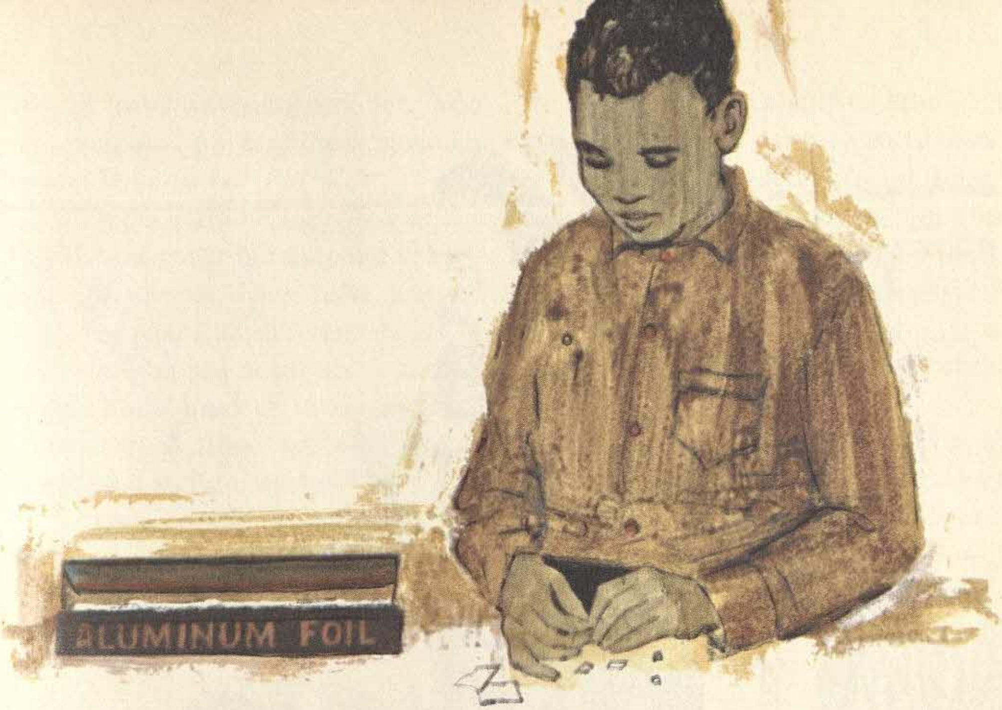
Aristotle

many men. Elements were discovered and named. In 1661, the British scientist, Robert Boyle provided additional experimental evidence to show that there were more than four elements and that earth, air, fire, and water were not necessarily among them. He also gave a definition which helped to identify a substance as an element. To be an element, a substance had to be pure, and not formed from a combination of other elements. The idea began to take hold that other pure substances called *compounds* existed. These compounds were themselves made of elements.

In 1808 John Dalton, an English schoolteacher and chemist, showed that different elements had different weights. He demonstrated this discovery by first weighing a compound. He then separated the compound into its elements and weighed each element separately. In this way he found that some elements were heavier than others. He could not weigh just one atom of an element, but he could compare the weights of the many elements he separated. He arranged them in an order according to their weights and found that the lightest element was hydrogen.

Dalton improved the atomic model of Democritus. Dalton believed that atoms of a particular element were unlike the atoms of any other element. He further believed that changes from one substance to another could be explained if atoms





remained unchanged both when they combined to form new substances and when they were separated from compounds.

The ideas about atoms have changed through the years as scientists discovered more and more information about them. A mental model of atoms began to take shape. As new ideas concerning atoms were suggested, the model became more and more useful. The atomic model you will learn about in this unit will change in the future, but for the present it will provide you with a way to begin understanding atoms.

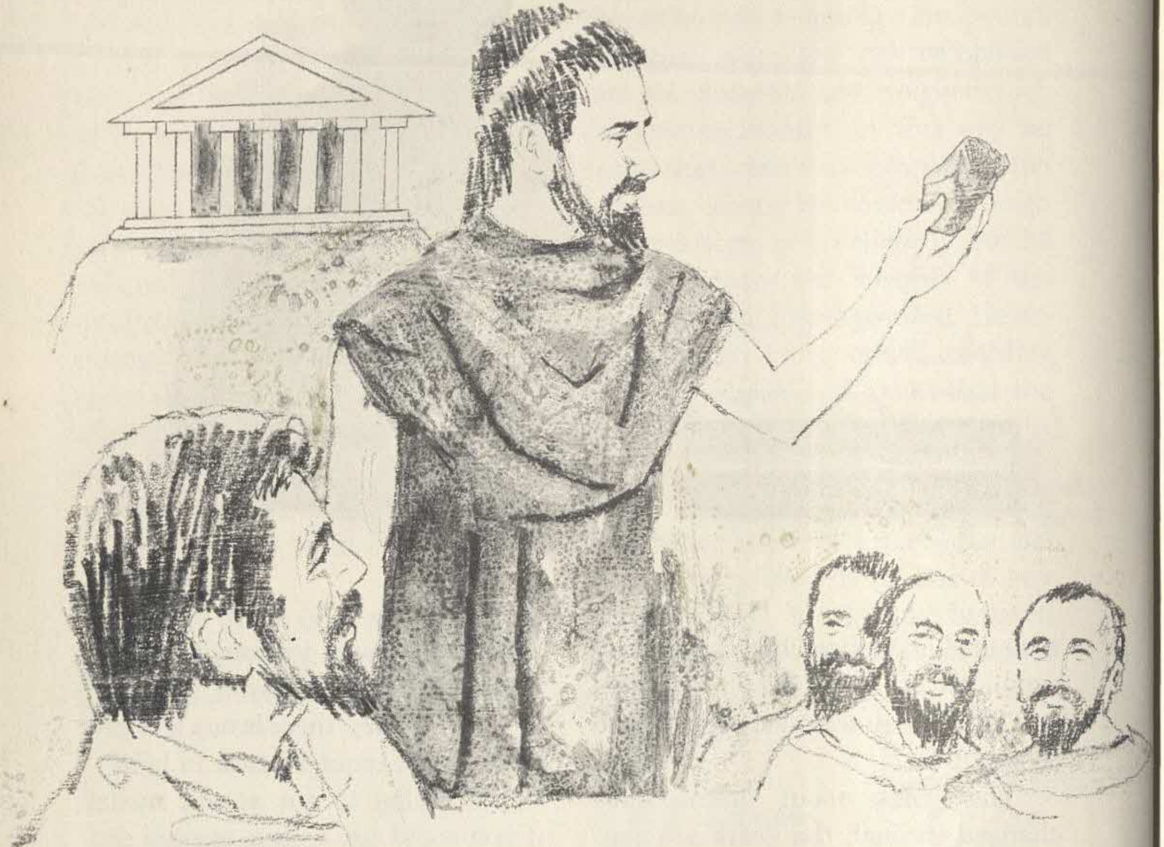
A Closer Look at Atoms

What would happen if you took a small piece of a substance and tore it in half, and then tore the half in half, and kept on tearing it in half? Would it become too small to hold? Could you keep on tearing it in half? Do you suppose there is one last tiny piece that cannot be torn in half?

According to our atomic model, if you could cut a piece of pure copper in half, until you came to the last tiny piece, you would find, if you could see it or test it, that the last piece would still be copper.

We can recognize copper as an element by its own set of characteristics. These characteristics are called the element's *properties*.

The *physical* characteristics of a material are those properties used to describe its physical make-up. Hardness, odor, color, and shininess are a few examples of physical characteristics. Chalk, although it is not an element, might be described as a hard, white, odorless substance.



It crumbles, will not stretch, and cannot be rolled or pressed into sheets. All such terms that physically describe a material are its physical characteristics. What are the physical characteristics of a crayon? Does an ice cube have physical characteristics? If you were to cut a piece of iron into smaller pieces, the last tiny piece would be iron. It is possible for some scientists to split this last piece into even smaller pieces, but when they do, the remaining parts no longer have the properties of iron.

This last piece of a substance is called an *atom*. The smallest piece of copper is a copper atom. The smallest piece of gold is a gold atom. What is the smallest piece of iron called?

Democritus wondered what the smallest part of a substance would be like. He believed that the atom was the tiniest piece of a material that still had the characteristics of that material. To Democritus, the word atom had a little different meaning than it does to us. It meant a part of something that could not

be cut into anything smaller. You can imagine how tiny these particles would have to be.

Many scientists from all over the world have contributed to our knowledge of atoms. They have learned that there are 92 different kinds of atoms which are naturally found on earth. Each kind of material made from one of these types of atoms is called a *natural element*.

There are 11 "man-made" elements too, bringing the number of elements up to 103. You will study more about these elements later. For now, it will be easier for you to think of the first 92 elements by themselves. A very tiny piece of the element copper is made up of billions of copper atoms. A tiny piece of silver is made of billions of silver atoms. What do you think a piece of gold is made of?

Scientists have arranged a list of the atoms of the 92 elements. They have numbered and named each one in a very sensible way, as you will soon see.

Silver

Copper

Iron

Gold

Listed below are the names of some of the 92 natural types of atoms. Read over the list. Are some of the names familiar to you? Are there some that you have never heard of?

Some of the Atoms

The Atomic Number	The Name of the Element
1	hydrogen
2	helium
3	lithium
6	carbon
7	nitrogen
8	oxygen
11	sodium
13	aluminum
14	silicon
16	sulfur
17	chlorine
20	calcium
25	manganese
28	nickel
29	copper
30	zinc
47	silver
50	tin
53	iodine
79	gold
80	mercury
82	lead
88	radium
92	uranium

DESCRIBE

Collect some objects made of various elements and bring them into class. Iron nails, copper wire, aluminum tubing or foil, and lead pipe are a few examples. Describe these elements and compare their physical characteristics. Make a list of the elements you have and write down as many physical characteristics as you can for each. Are some characteristics common to more than one element?

Each of these substances has its own physical characteristics, just as a balloon, or a banana, or a pencil has its own characteristics. Because each substance has its own physical characteristics, it is described in a different way.

ACTIVITY

Take a piece of coal and make a detailed list of its characteristics. Use a knife or chisel to cut a small piece from the lump of coal. Does the small piece have the same physical characteristics as the original piece? You can make even smaller pieces of coal with a file or sandpaper. Do the filings have the properties of the original lump?

By crushing a piece of coal and rubbing it between two pieces of paper, you can make a very fine dust of coal particles. What are the properties of the dust particles? Are they still coal? Can you tell anything about the size of atoms from this activity? □□

Scientists use a shorthand type of lettering to write about the atoms. For carbon they use the letter C. For hydrogen the letter H is used. What do they use for oxygen? The letters used in the scientist's shorthand are called *chemical symbols*. What is the symbol for iodine? For uranium?

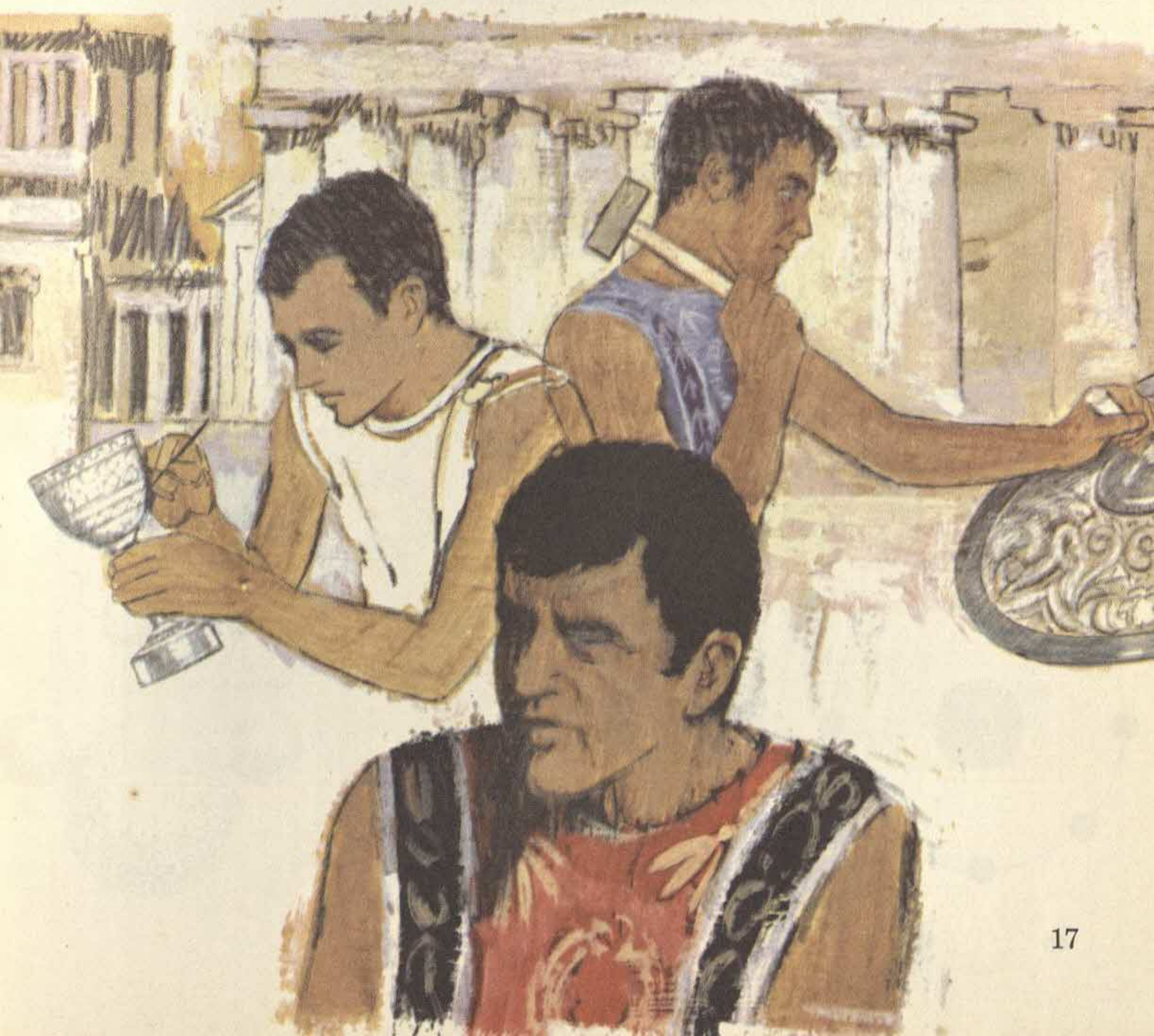
Sometimes the names for more than one atom begin with the same letter. For example, hydrogen and helium both begin with H. Could the same symbol be used for each? If H is used for hydrogen, what could you use for helium? If C is used for carbon, what could you use for calcium? If S is used for sulfur, what could be used for silicon? What symbols are actually used?

Men knew about some of the substances on the list in very early times. Romans and Greeks made a great deal of use of gold and silver. They also knew about mercury. Because these people spoke Latin and Greek, they used different words to name the substances. Gold was called Aurum (OHR-um) by the Romans. Silver came from the Latin word Argentum (ahr-JEN-tum). Iron came from the word Ferrum (FER-um). Today scientists use the symbols Au for gold, Ag for silver, and Fe for iron. Why are these symbols used?

There are 11 symbols which came from Latin words. See if you can find some interesting stories about the names and symbols for lead, mercury, and tin.

Atomic Models

Atoms are extremely small. One ordinary drop of water contains more than 100 billion billion atoms. Not even scientists can imagine such a large number. It would take many more than 100 billion billion atoms to make a small piece of gold or a small piece of lead that you could



hold in your hand. Atoms are so small that it would take *all* of the people in the world *all* of their lifetimes (without taking time to eat or sleep) to count the number of atoms in a grain of sand.

We know a great deal about atoms, and yet we cannot see them. Based upon our knowledge, we can build an imaginary model that may help to develop a better understanding about atoms. Later perhaps a better, more accurate, model can be developed based upon our increased knowledge.

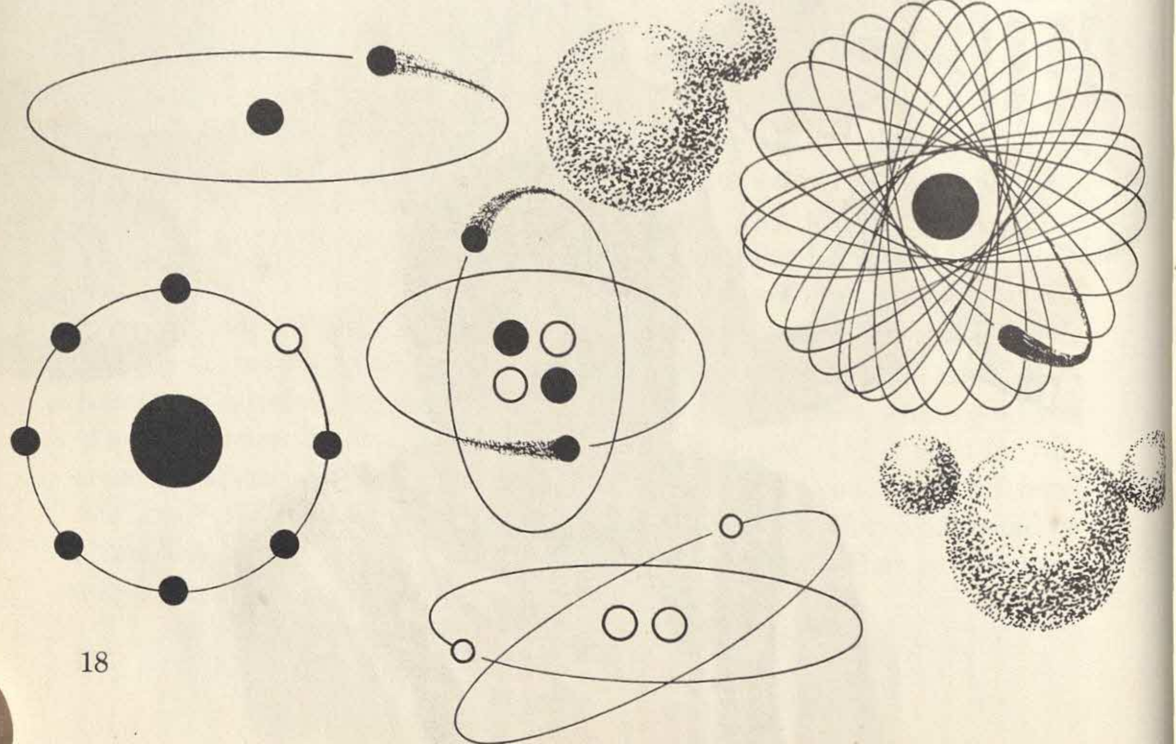
Remember, a model is something which man creates; it is not the real object. Let's try to build a model of atoms.

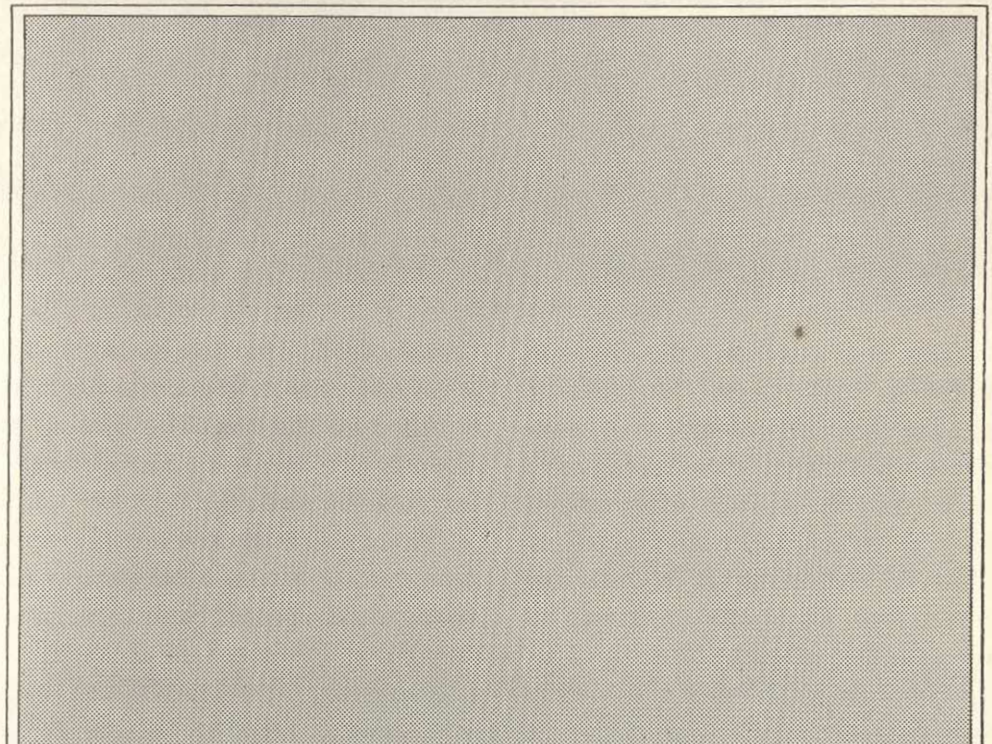
On the opposite page are printed about one hundred thousand (100,000) dots. Try to look at as many as you can using a magnifying glass. How many pages of dots would it take to make 1 million? 10 million? 100 million? 1 billion?

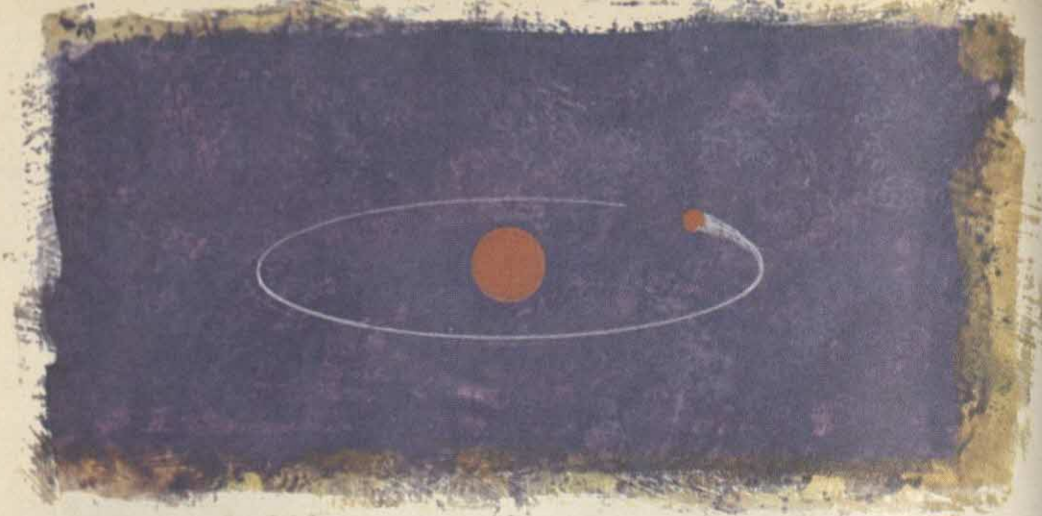
If atoms could be lined up in single file, about 100 million of them could be placed along a line segment one inch long. If each dot on the page represented one atom, how many pages of dots would you need to represent the number of atoms in a one-inch line segment? Look at a single dot. There are about 1,000,000 atoms which could be lined up to go across the dot. How many pages of dots would represent this many atoms?

Now you will explore the imaginary model which scientists have made to help them understand more about the atom.

You have probably seen pictures similar to the ones shown below. Let's see what they mean.



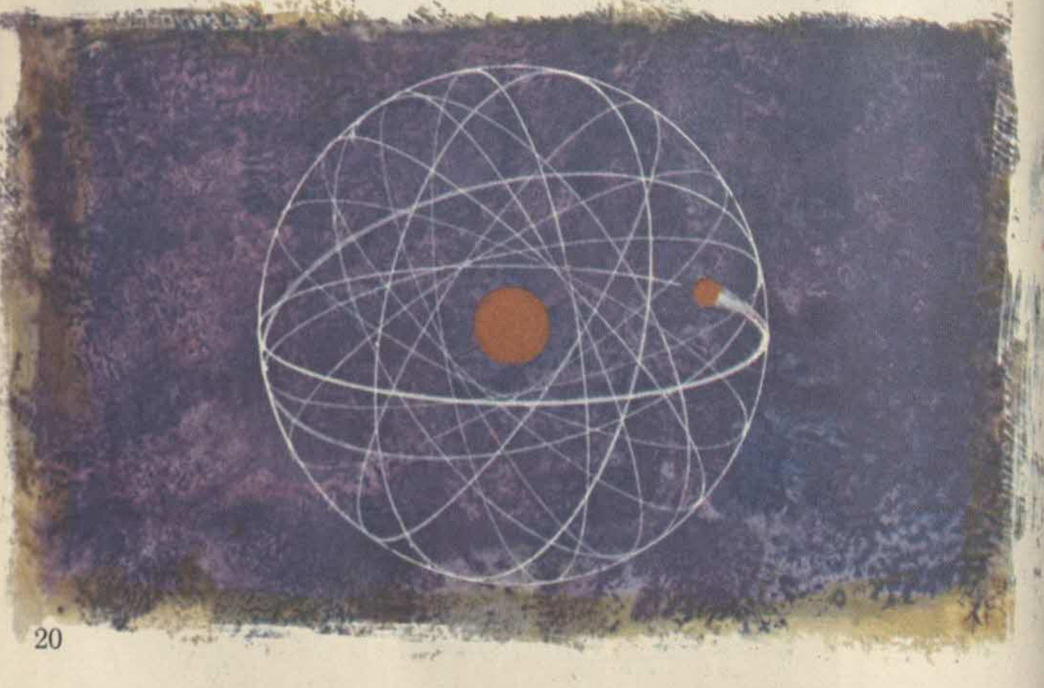




The first atom on your list was hydrogen (H). It is the smallest particle that still resembles the substance hydrogen. Scientists have found that if an atom of hydrogen were taken apart, it would no longer resemble hydrogen. It is now believed that all atoms are made of even smaller pieces.

The two particles that make a hydrogen atom are shown in the picture above. The particle in the center is called a *proton*. The outer particle is called an *electron*. The proton in the center of the atom is much heavier than the electron.

According to this model, the electron moves around the proton at tremendous speeds. Scientists have calculated the speed of these moving electrons and found that they travelled at speeds close to 1,300



miles per second. This would mean that a moving electron could make billions of trips around the proton in one second. The path of the electron, according to this model, has been called an orbit. Can you think of other things that move in orbits?

The second atom on your list is helium (He). This is the gas used to fill the balloons you can get at the circus or at a fair. Balloons filled with helium rise in the air. One of the physical characteristics which makes helium different from other gases is its extreme lightness. Does the behavior of helium-filled balloons demonstrate this characteristic? Would a hydrogen-filled balloon also rise in the air?

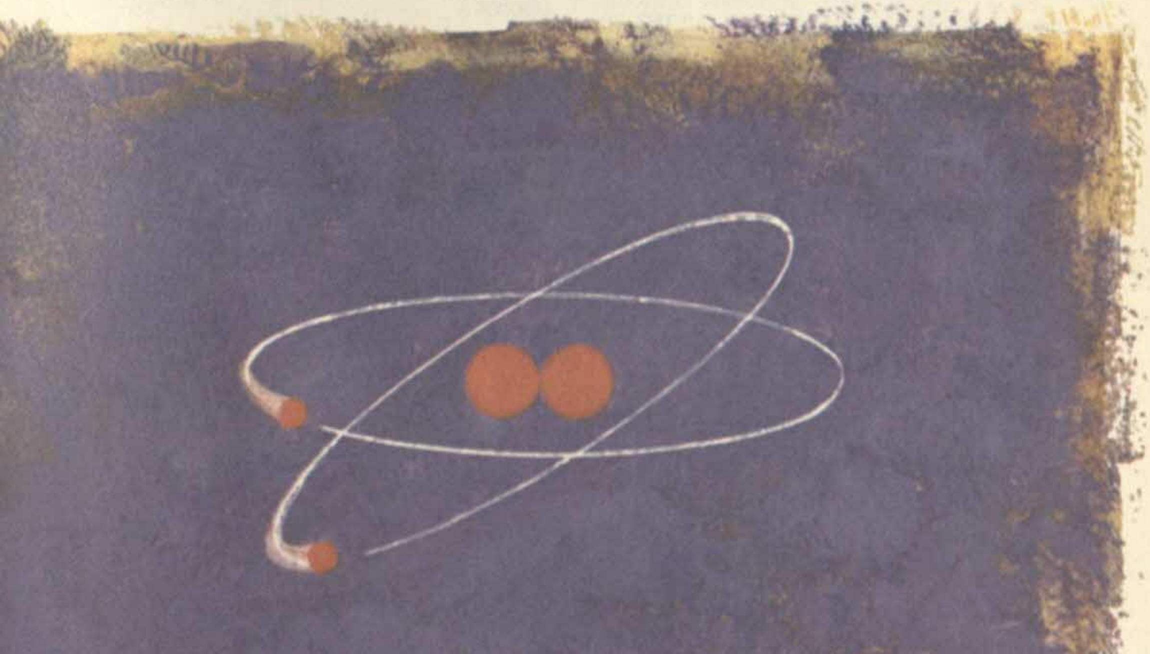
A picture of a helium atom is shown below.

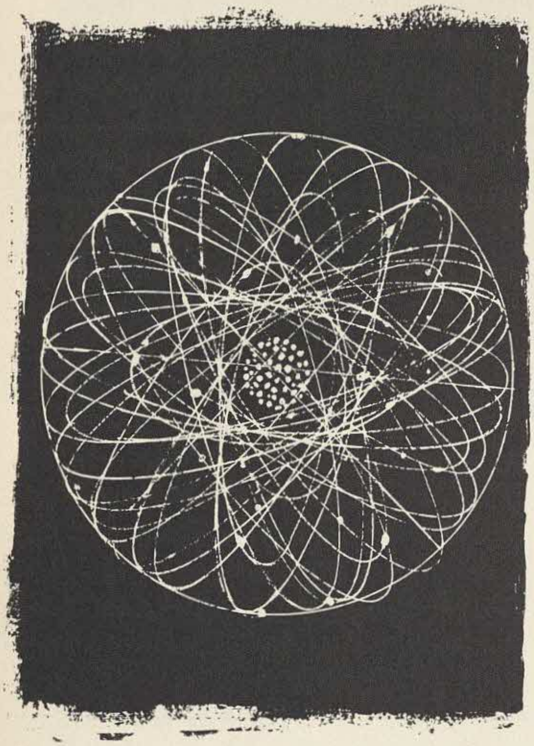
According to this model, the helium atom would have 2 protons in the center and 2 electrons orbiting around them.

What was the third element on your list? How many protons would an atom of the third element have? How many electrons? Do you see a connection between the element number and the particles making up the atomic model?

What is the name of element number 8? How many protons would it have? How many electrons? What is the symbol for atom number 8?

How many protons would be in the center of a uranium atom? How





many electrons would it have? What number is uranium? Do you think a uranium atom is larger than a hydrogen atom? Why?

In experiments that took place after 1900, scientists had good reason to believe that the proton and electron numbers of the model were correct. As you will discover later in the unit, the model was far from complete.

Do the numbers of the elements tell you anything about their atoms? Have the scientists arranged the atoms in a sensible way?

The number given to an atom is called an *atomic number*. If you know an atom's atomic number, what do you know about its electrons and protons?

ACTIVITY

Using marbles to represent protons, and paper clips to represent electrons, construct models of some of the atoms on the list. How many marbles do you need to make a model of a nitrogen atom? Have a guessing game with the other students in your class. After writing down the names of your atom models, see if you can tell what atom models your classmates have constructed. Did they guess what atom models you made?

Since you and your classmates all learned to use the same model, you will find that it can be used to identify the atoms of various elements. Do you think the model is more useful if it can describe all kinds of atoms?

Atoms and Electricity

When you constructed models of atoms in the last activity, you always put an equal number of protons and electrons in each model. When the number of protons and electrons in an atom is equal, we can say that the atom is "balanced." It is possible, according to this model, to "unbalance" atoms by brushing or rubbing away electrons from the atom. Can you rearrange one of your models of an atom to make it unbalanced?

Have you ever walked across a wool rug and then touched a doorknob or metal lamp? What happened? Did you ever slide across the plastic seat of an automobile and then touch the door handle? What happened?

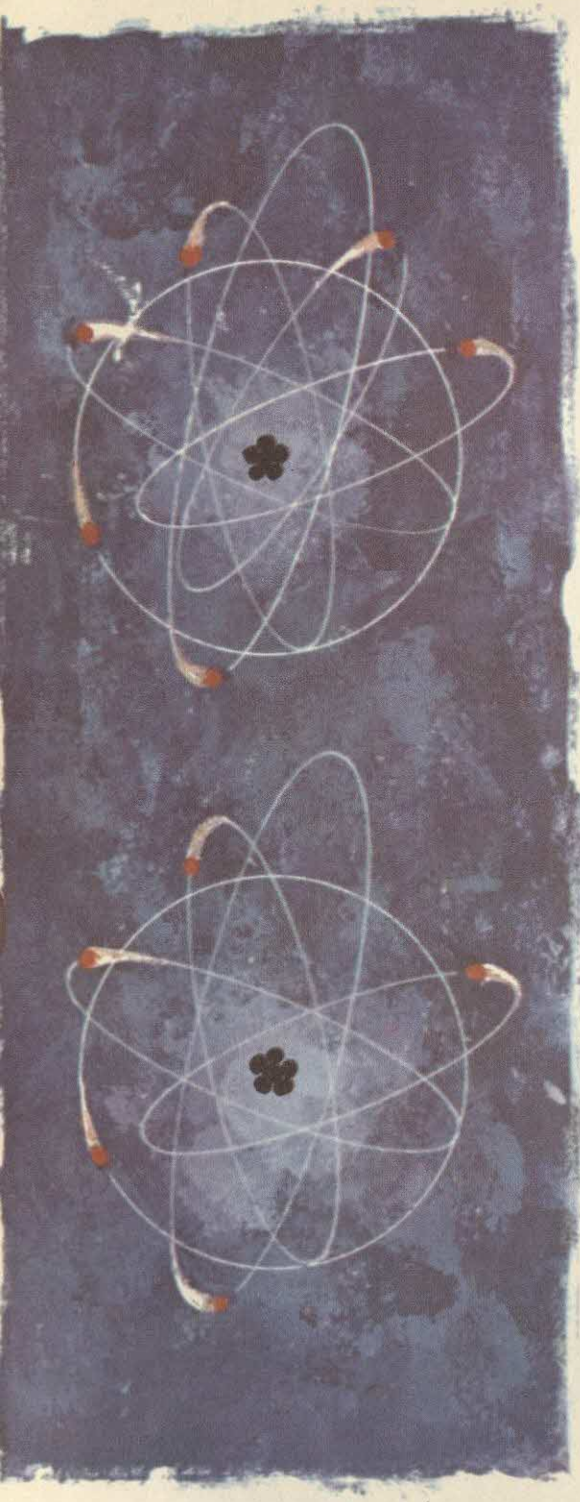
In each of these cases, if our model is correct, you may have brushed some electrons away from their atoms. According to our model of the atom, would it be easier to brush away protons or electrons?

EXPLORE

Rub a comb or pen briskly against some wool clothing. Bring the comb near some tiny bits of paper. What happens? Rub the comb again and bring it near a thin stream of water running from a faucet. What happens?

What would happen if you rubbed the comb with a different material?

In this activity, according to our atomic model, you have rubbed



electrons from the atoms in one object and transferred them to the atoms in another object. How did the objects behave when this happened?

Of course you would have to have rubbed the electrons from millions upon millions of atoms. Let's look at the model of one particular kind of atom to see what might have happened.

Look at the carbon atom shown. Is it balanced? How can you tell?

Scientists have found that electrons and protons carry electric charges. To indicate that the charges on electrons are different from the charges on protons, scientists say that electrons have negative (−) charges and protons have positive (+) charges. We can add this information to our model.

When there are as many negative charges in an atom as there are positive charges, the atom is called *neutral*. How is a neutral atom similar to our balanced atom? Is the carbon atom in the picture neutral? Is it balanced?

If one electron were brushed away from the carbon atom, it might look like the picture at the left.

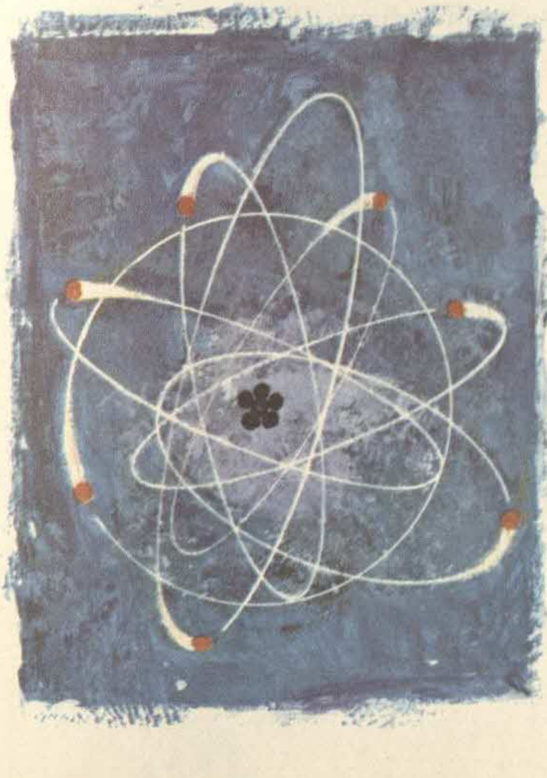
Is the atom neutral? Are there more negative charges than positive charges? When there are more positive charges than negative charges, the atom is said to have a *positive charge*. Is this positively charged atom neutral?

When an electron is rubbed away from one atom, the electron might be

picked up by another atom. Below is a carbon atom that has picked up an extra electron. Is this atom neutral? If the atom has more electrons than protons, it is said to have a *negative charge.*

When an atom picks up an electron, and therefore has an extra negative charge, the atom is called a *negative ion.* When an atom has lost an electron the atom has an extra positive charge and is called a *positive ion.* Any atom that has lost or gained an electron and is no longer neutral is called an *ion.*

Scientists have found that atoms tend to be neutral. Whenever an atom has lost an electron, it attracts another electron, if one is available, and becomes neutral again. How do you think an atom would behave if it gained an extra electron?



ACTIVITY

Blow up a balloon and rub it with a piece of wool cloth. Bring the balloon close to your face, but do not touch your face with the balloon. What do you feel? Do you hear anything?

Our atomic model can be used to explain this activity. What you feel and the crackling noise that can sometimes be heard with it would be caused by a flow of electrons from the balloon to your face. When you rubbed the balloon with the wool, electrons would be rubbed off those atoms making up the wool, and would move onto the atoms that make up the balloon.

OBSERVE

Collect several plastic rulers and a roll of plastic sandwich wrap. Tie a string about 8 inches long around the middle of one ruler and hang it from a stand as shown in the illustration. Move another ruler slowly toward the hanging ruler so that they are about an inch apart. Does anything happen? Now rub the hanging ruler very hard with the piece of sandwich wrap about 30 times. Also rub another ruler with the sandwich wrap the same way, and then bring it close to the hanging ruler. What happens this time?

Repeat this activity several times using the same, then different rulers. Does the same thing happen each time? Repeat the activity using different plastic wraps.

When you rubbed the hanging ruler with sandwich wrap, electrons were rubbed off the ruler onto the wrap. What kind of charge did the ruler have? What charge did the wrap have? □□

The second ruler behaved in the same way as the hanging ruler, losing electrons to the wrap, so it too had a positive charge. When you brought the two rulers close together, you observed one of the two basic rules about charges: *Charges that are alike push away from each other.* How does this rule depend on our model?

EXPLORE

Follow the same procedure as was used in the previous activity but substitute a piece of wool cloth for the sandwich wrap.

After rubbing the hanging ruler with the wool, rub another ruler and bring the two close together. What do you observe? Do the rulers behave as they did in the last activity? □□

This time, when the rulers were rubbed with the wool, electrons were rubbed from the wool onto the rulers. What charge was on the rulers? Did they both have the same charge? What happened when you brought the rulers together?

In the last two activities the reaction of a positive charge to another positive charge was the same as the reaction of a negative charge to another negative charge. Would you agree that like charges push away from each other? What do you think will happen when unlike charges are brought together?

PREDICT

Rub the hanging ruler with the sandwich wrap. What charge does it have? Now rub another ruler with the wool cloth. What charge does this ruler have? Before bringing the two rulers together, see if you can guess what will happen by using your model of atoms.

Very slowly move the rulers close together. Was your guess correct? Repeat this activity several times to see if the reaction is the same each time. □□

When a negatively charged ruler is brought close to a positively charged hanging ruler, you can observe the second basic rule about charges–*unlike charges attract each other.* Does this rule about charges support your imaginary atomic model? What do you think keeps the electrons of an atom near the protons? The behavior of electrons in this way is called *static electricity.* Does our atomic model help to explain static electricity?

EXPLAIN

Can you use your knowledge of charges and the atomic model to find out what happens when various materials are rubbed together? Rub the hanging ruler with wool. Now rub a glass rod with a piece of silk cloth.

When the glass rod is brought near the ruler, what happens? What kind of charge is on the glass rod? Can you now explain what happened to the atoms when the glass rod was rubbed with the silk? Repeat this activity using various types of materials. How can your atomic model be used to predict what will happen in a new situation?

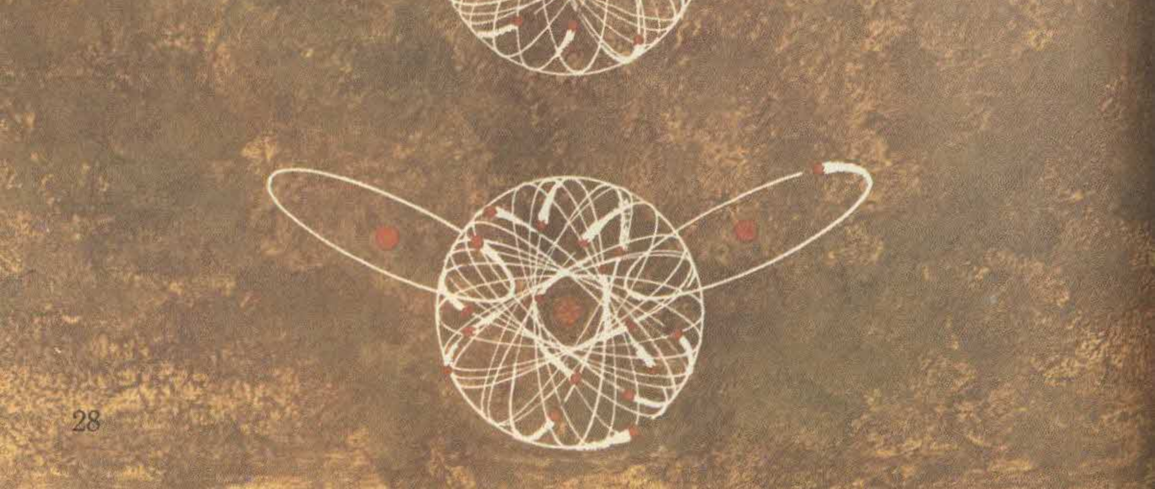
Molecules and Compounds

Your model depends on the belief that a piece of an element can be broken into ever smaller pieces, with the smallest piece still having all the properties and characteristics of the element. This fundamental piece is called an atom. You can use this model of an atom to see how it can explain some of the behavior of matter. Your atomic model can be used to explain static electricity but, to do so, the atom had to be made of still tinier particles which we have called protons and electrons.

Many of the different kinds of materials you see around you are not composed of only one element. Can you find sugar on your list of elements? Can you find salt on the list? Is wood an element? In order to explain how these substances behave, we must again add to our model.

You read that there are 92 different kinds of natural elements. Yet you can probably make a list of different materials that has many more than 92 items on it. How can you explain this?

Can substances be made of more than one kind of element? Carbon, hydrogen, and oxygen are elements. When they combine, they form a new substance called sugar. The elements sodium (Na) and chlorine (Cl) combine to form the substance salt



(NaCl). Is water an element? Is it formed by a combination of elements? Does water have the same physical properties as hydrogen and oxygen?

Substances that are formed by the combination of two or more of the 92 natural elements are called *compounds*. In our model of the atom, the smallest part of an element is an atom. In a similar way, we can create a model for compounds in which there is a smallest part that still resembles the original compound. This smallest part of a compound is called a *molecule*. If a molecule of a substance is broken into pieces any smaller than a molecule, what do you suppose will be left? What physical properties do you think the remaining pieces will have?

If compounds are made up of tiny particles called molecules, we should be able to test our model to see if a substance will behave as though it were made of particles.

EXPLORE

Your teacher will give you some crystals of potassium permanganate. Examine some of the crystals carefully to determine their physical characteristics. What color are the crystals? Now drop several of the crystals into a very large beaker of water. Observe the beaker for several minutes. Do you see any change in the water? Do you recognize the color? What does this spreading of color mean to you? Does it help support our model of molecules?

OBSERVE

Place some water in a beaker and mark the level with a crayon. Bring the water to a boil on a hot plate. What do you observe? After the water has boiled for several minutes, remove the beaker from the heat so that the boiling will stop. Is the water level the same as it was before you boiled the water? Where do you think the missing water might have gone? Did you see water rising from the boiling water? Why can't you see the missing water?

Put the beaker back on the hot plate and bring the water to a boil again. When steam begins to rise rapidly from the water, hold a mirror in the highest part of the cloud of steam for two or three seconds and then remove it. Does the mirror have small beads of liquid on it? Can you identify the liquid? Does the model of molecules help to explain the behavior of water and steam that you have observed?

The Size of Molecules

Molecules would, in most cases, be larger than atoms because they are made up of several atoms that are joined together to form a substance. Every natural substance on earth would be made from atoms or some combination of the atoms of the 92 different kinds of natural elements. There are many combinations of these elements that are possible. This would explain why there are so many different kinds of compounds and mixtures of compounds.

Although molecules are usually larger than atoms, they would still be very small, and it is very hard to get a picture of their actual size. If you could change each molecule in a glass of water to a single grain of sand, you would have enough sand to cover the entire United States with a layer 100 feet deep. In spite of their small size, the number of molecules that would be in a solution can be estimated.

INVESTIGATE

Obtain an eyedropper, a bottle of black ink, and several one quart jars. With the eyedropper, count out ten drops of ink into a jar. What does it look like? Now place ten drops of ink into a quart-sized jar full of water. Is the water in one jar darker than the other? Do you know why? Now put five drops of ink into a third jar. How does this color compare with the other colors? If you

were to add a quart of water to the five ink drops, what do you suppose would happen to the color? How would this color compare with the color resulting from 10 drops of ink added to a quart of water? Try to answer these questions by experimenting.

What would happen to the color of the liquid if you kept on dividing the number of ink drops in half over and over again? Save these three jars of ink solution. You will be able to use them in the next activity.

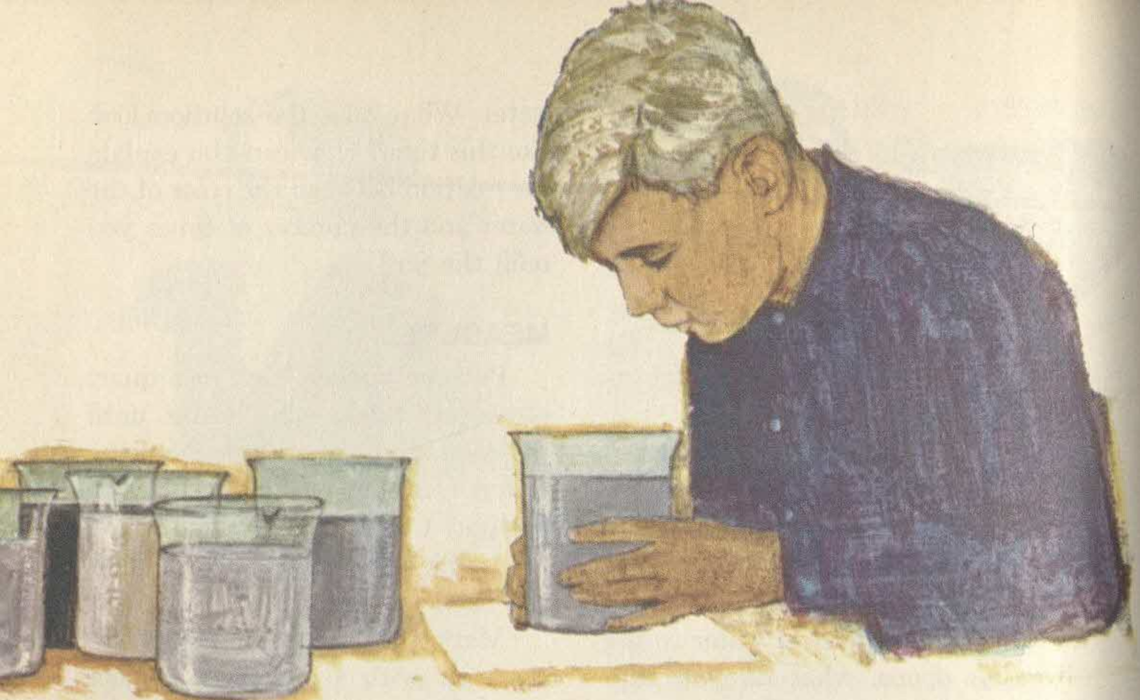
OBSERVE

Put ten drops of ink into a quart-sized jar of water. What color is the water? Now pour off half of this solution and add clean water to the half remaining until the quart-sized jar is full again. What color is the solution now? Which of the jars in the last activity does this jar look like? Pour off half of this solution and again refill the jar with clean water. What does the solution look like this time? How can you explain the relation between the color of the water and the number of times you refill the jar?

MEASURE

Put one ounce of ink in a quart of water. Shake the bottle until the color seems even throughout the water. Can you see the particles in the ink? Could you see them if you used a microscope? How do you know the particles are there?

Mark the middle of the quart-sized jar with a crayon or a piece of tape. Pour away half of the solution and fill the jar again by adding clean water. Shake the jar. What happened to the color? Are there still



particles of ink in the water? How can you tell? Are there as many particles as when you started? How much ink is in the solution now?

Pour out half of the solution again and refill the jar with clean water. What happened to the color? Each time you replace half of the solution with water, you cut the amount of the ink in half. How many times can you repeat this procedure and still see some of the color of the ink in the solution? As the ink solution becomes lighter, it might be easier for you to see the ink by putting the jar of solution on a piece of white paper. After you do this, look down through the opening of the jar.

The simple table shown at the right will help you to see how much ink is left in the solution after each time you repeat the process described above.

Number of Pourings	Amount of Ink Left in Solution
1	1/2 ounce
2	1/4 ounce
3	1/8 ounce
4	1/16 ounce
5	1/32 ounce
6	1/64 ounce
7	1/128 ounce
8	1/256 ounce
9	1/512 ounce
10	1/1024 ounce
11	1/2048 ounce
12	1/4096 ounce
13	1/8192 ounce
14	1/16,384 ounce
15	1/32,768 ounce
16	1/65,536 ounce
17	1/131,072 ounce
18	1/262,144 ounce
19	1/524,288 ounce
20	1/1,048,576 ounce

If you are still able to see the ink in the water after 7 pourings, the amount of ink left shows that there were at least 128 parts of ink to the original ounce of ink. Do you know why? If, after 10 pourings, you can still see the ink, there may have been more than 1,024 parts of ink to the original ounce.

Can you see the ink after 20 pourings? What part of an ounce is left in the water now?

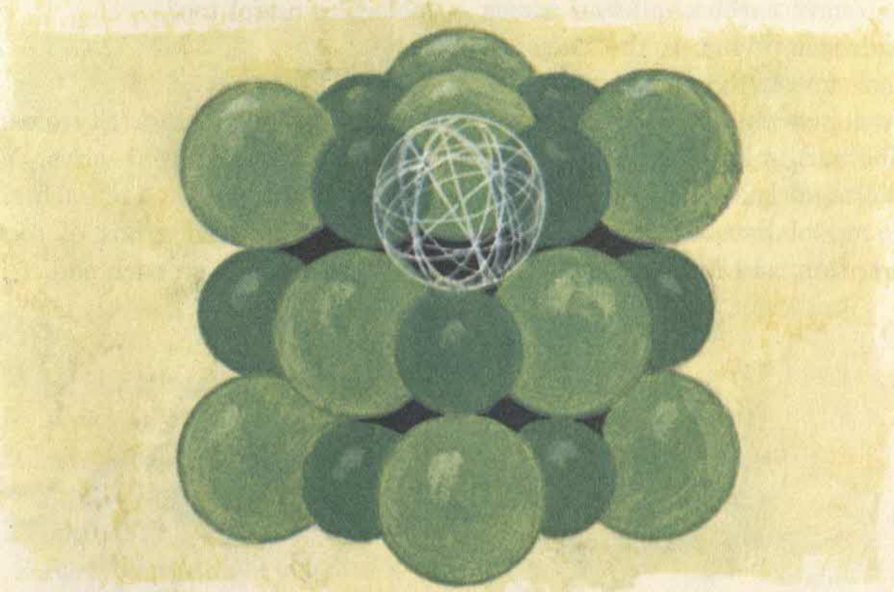
Try the same activities with some other colorful liquids such as iodine, Easter egg dye, or some vegetable coloring. Does it seem correct to assume that these liquids are made of molecules?

A Closer Look at Molecules

Now we will look more closely at molecules of some common compounds. We will use our scientific shorthand to help us.

Salt is made up of two kinds of atoms, sodium (Na) and chlorine (Cl). It would take one atom of sodium joined to one atom of chlorine to make one molecule of salt, if salt were made of molecules. The chemical symbol for salt is NaCl. Can you tell why this symbol is used?

One water molecule is made from two atoms of hydrogen joined to one of oxygen. The symbol for water is H_2O. What do you think the H_2 means?



If we had, for example, 11 molecules of water, we could write in our shorthand 11 H_2O. How many hydrogen atoms would be found in 11 water molecules? Can you tell how many oxygen atoms there are in 11 water molecules? Could 11 H_2O also be written as $H_{22}O_{11}$? Why do you suppose 11 H_2O is written instead?

A sugar molecule is made of 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms. The chemical symbol for sugar is $C_{12}H_{22}O_{11}$. How many atoms of carbon, hydrogen, and oxygen would be in three molecules of sugar?

A molecule of a gas called methane, which makes up over 90 percent of the natural gas used in homes for stoves and furnaces, is made of one atom of carbon and four atoms of hydrogen. What is the chemical symbol for methane? A substance called copper sulfate, used in electroplating and to kill tiny living things in polluted lakes and streams, is made up of one copper atom, one sulfur atom, and four oxygen atoms. What is the chemical formula for copper sulfate?

How many carbon and oxygen atoms are in 5 CO_2? How many molecules of carbon dioxide is this?

What atoms would be found in the following compounds?

$CaCO_3$	$FeSO_4$
$AlCl_3$	$CaCl_2$
$AgNO_3$	Na_2SO_4

How many of each atom are in each compound? The chart on page 15 may help you with the names.

Molecular Models

The atomic model can explain the behavior of atoms and their electrons. Also, the atomic model can be used as a scientific tool. Is a model for molecules useful too?

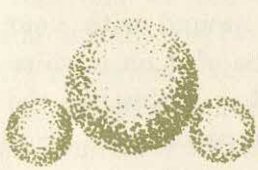
ACTIVITY

Obtain polyfoam (Styrofoam) balls of three different sizes. You will need about twelve of each size. You will also need a box of toothpicks with points on each end.

Each of the smallest polyfoam balls will represent *one hydrogen atom*. Each of the middle-sized balls will represent *one carbon atom*. The largest balls will represent *oxygen atoms*. Why do we choose the smallest ball to represent the hydrogen atom? Why is the oxygen atom the largest?

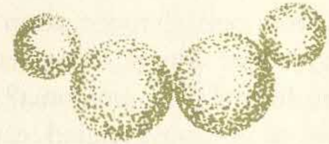
A single molecule of water is made up of two atoms of hydrogen and one atom of oxygen. Which atom is the larger? Do you remember why?

Insert two toothpicks into the centers of two of the small polyfoam balls. Take a large polyfoam ball and attach it to the toothpicks so that it looks like this:



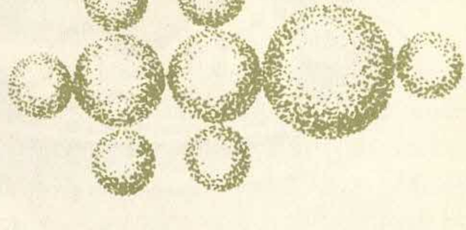
This is a model of a water molecule. Write an H on the balls representing hydrogen. What is the symbol for oxygen? Put this symbol on the ball representing oxygen. □□

Have you heard of a substance called hydrogen peroxide? Can you describe it? Do you know how it is used? The chemical formula for hydrogen peroxide is H_2O_2. Make a model of a hydrogen peroxide molecule. Label the hydrogen atoms and the oxygen atoms with the proper symbols. Does your model for this molecule look like this?



Carbon dioxide is a gas you have probably studied in your earlier work. The chemical formula for one carbon dioxide molecule is CO_2. Make a model of the carbon dioxide molecule.

There are many other molecules that are more complicated but are very interesting to construct. Ethyl alcohol is found in liquors and some medicines. Its chemical formula is C_2H_5OH. A model of an ethyl alcohol molecule looks like this:



You can see that there are many possible substances which can be made using only three different types of atoms—hydrogen, carbon, and oxygen. Many other substances are formed from other atoms as well. Ammonia dissolved in water is often used as a cleaning fluid. Ammonia is formed from one nitrogen atom and three hydrogen atoms. What is the chemical formula for ammonia? One molecule of a liquid called carbon tetrachloride, commonly used in fire extinguishers and in dry cleaning clothes, is made up of one carbon atom and four chlorine atoms. What is its chemical formula?

Carbon is an element. Sometimes carbon atoms are joined to atoms of other elements to form compounds. Each carbon compound has different properties, depending upon how the different atoms are joined with the carbon atoms. For example, bread, pencil lead, cotton cloth, and wood do not seem to have anything in common, yet each of these substances contains carbon atoms joined to other types of atoms.

It is possible to identify some of the atoms in the molecules of a compound with some simple tests. Using our model of molecules we can explain why the tests work. Do the following activities and see if our molecular model helps to explain what you observe.

DESCRIBE

Burn a piece of paper in a dish. Look at what is left. What color is it? When it has cooled, push it around with your fingers. Rub some of it on a white piece of paper. Describe its physical characteristics.

Light a wooden match and let it burn in a dish. Look at what is left. What color is it? When it has cooled, push it around with your fingers. Rub some of it on a white piece of paper. How is this like the remains of the burnt paper? □□

The substance left after burning the paper and the match was carbon. The black particles are evidence that carbon was one of the elements that made up the paper and the match. Its appearance and the way it feels are physical characteristics of carbon. Remember them.

ACTIVITY

It is possible to find out what elements are in certain material things by using a flame.

Straighten a paper clip and put a small loop in one end so that it will hold substances.

Hold the paper clip with a pair of pliers so that your fingers will not be burned. Now hold the paper clip in the flame until it does not cause a change in the color of the flame. If the flame changes color, this probably means that the paper clip is not clean.

When the paper clip is clean, put a small piece of bread on the loop. Use a pair of pliers to put the loop into the flame. As the bread burns, what do you see? What color is the bread? Have you seen this substance before? What is it?

Clean the paper clip again and attach a piece of cotton cloth to the loop. Use a pair of pliers to put the loop into the flame. What do you observe? Did the cloth material contain carbon atoms? How could you tell? □□

The test that you have been using to identify carbon atoms in the molecules of various compounds is an important tool for scientists. Many other elements can be identified by the colors they make in a flame.

ACTIVITY

Using the pliers, put the loop of your paper clip into the flame to make sure that it is clean. Obtain a small amount of table salt and some boric acid.

Dip the loop on your paper clip into the table salt (NaCl). Make sure that the salt sticks to the loop. You will not need to have much salt on the loop because the flame test is very sensitive.

Hold the loop in the flame. Observe the flame carefully. What do you see?

You have just done a test for sodium. Any substance with sodium in it will make the color you observed in the flame. Is sodium part of the compound NaCl?

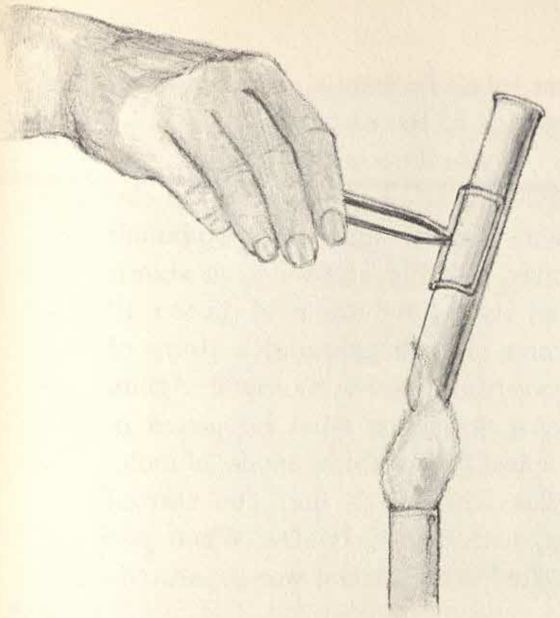
Clean the loop in the flame and dip it into some barium chloride.

Repeat the test that you did with the salt. What color do you observe in the flame? This is a test for the element barium which is one of the elements in barium chloride. Do all substances that contain barium make the same color in a flame?

You may not remember the color that appears in the flame for each element. Scientists may not remember either, so they keep a record of what they observe. You can keep a record for your flame tests by making a chart like the one below. Besides table salt and barium chloride, other substances are listed for you to test. Compounds containing these substances can be obtained from most drug stores and scientific supply houses.

Now that you have learned how to identify these elements by the flame test, you should test some un-

Substance to be Tested	Element which makes the color	Color of flame
Table salt $NaCl$	Sodium (Na)	
Barium chloride $BaCl_2$	Barium (Ba)	
Limewater $Ca(OH)_2$	Calcium (Ca)	



known substances such as eggshells, plaster, or baking soda to see what elements they might contain.

Besides the flame test, there are other ways in which you can learn about the elements that make up the molecules of compounds.

Do you remember what you read earlier about sugar? Is sugar a compound? Do you think you can test sugar to see what kind of atoms make up a sugar molecule?

OBSERVE

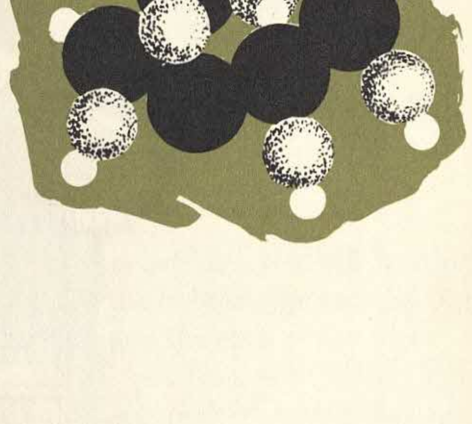
Put some sugar in the bottom of a test tube. Holding the test tube at an angle with a test tube holder, heat the sugar slowly over a flame. What do you observe?

Do you recognize the black substance in the bottom of the test tube? Is it carbon? What causes the moisture on the side of the test tube? If you did not keep the test tube tilted while you heated the sugar, you will have to repeat the test. Are the atoms found in water also found in sugar?

Would you agree that sugar contains carbon and the elements found in water? What elements make up water molecules?

Sugar contains the elements carbon, hydrogen, and oxygen. Through further tests, scientists have determined that each molecule of sugar contains 12 carbon atoms, 22 hydrogen atoms and 11 oxygen atoms. What is the chemical formula for a sugar molecule?

With your model of molecules, you can explain what happened in the test tube when you heated the sugar.



The sugar was separated into carbon and water. This separation can be written as:

$$C_{12}H_{22}O_{11} = C_{12} \text{ plus } H_{22}O_{11}$$

Do you recognize the $H_{22}O_{11}$? Is there another way this can be written? Could $H_{22}O_{11}$ be written 11 H_2O? Does this explain the clear liquid that appeared on the side of the test tube when the sugar was heated?

This same kind of test can be used to identify the elements in compounds other than sugar.

ACTIVITY

Obtain some corn starch and place a small amount in the bottom of a test tube. Keeping the test tube tilted as before, heat the starch over the flame.

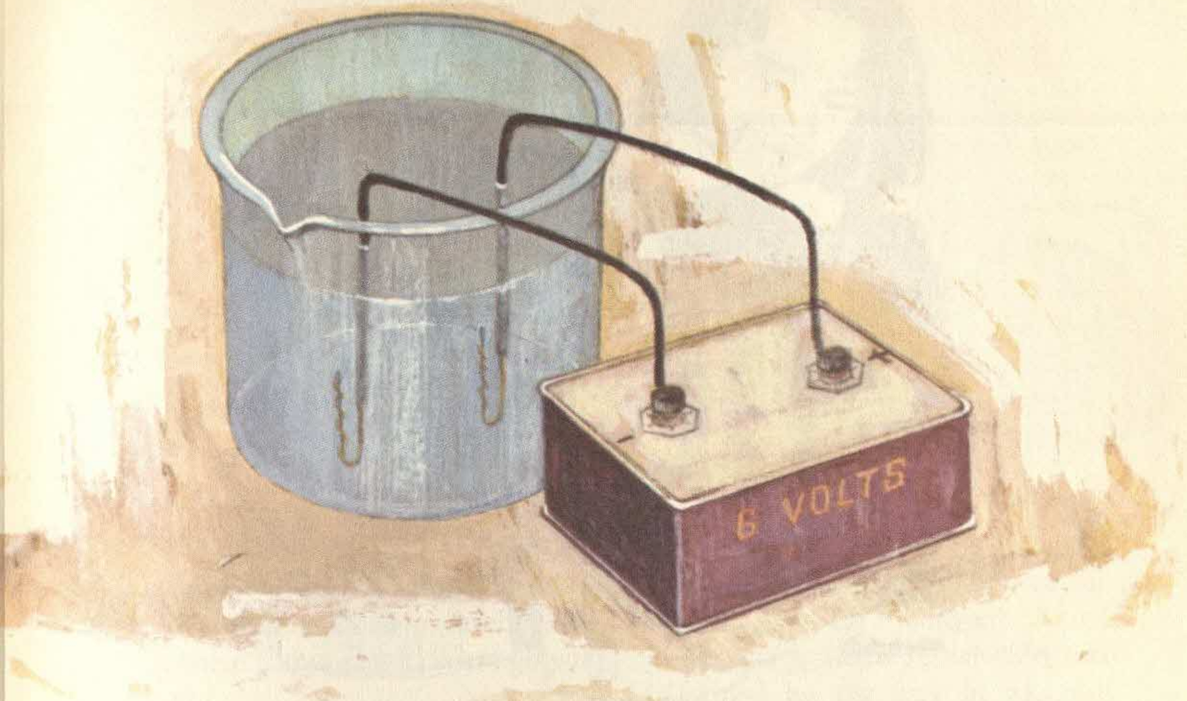
As you heat the starch, does the color change? How do you recognize the substance in the bottom of the test tube? Is there a clear liquid on the side of the test tube? □□

As was done with the sugar, you have separated starch into the element carbon and the compound water. Further studies have shown that there are 6 atoms of carbon, 10 atoms of hydrogen, and 5 atoms of oxygen in a starch molecule. Again, you can explain what happened in the test tube with the model of molecules. The starch that you started out with was $C_6H_{10}O_5$. When you heated it the carbon was separated:

$$C_6H_{10}O_5 = C_6 \text{ plus } H_{10}O_5$$

Do you recognize $H_{10}O_5$? Can it be written in another way? Is it water?

According to the molecular model, molecules are made from atoms of the elements. These elements combine to form molecules. When you burned sugar and starch and identified the remaining substances, you observed evidence indicating that a



molecule can be broken down into other substances with different physical characteristics. Both the burned sugar and the starch became carbon atoms plus liquid water. But water is a compound too. Do you think there is a way to separate water into the elements that make it up?

Breaking Down Water Molecules

ACTIVITY

Scrape about ½ an inch of insulation from each end of two pieces of wire; each piece of wire should be about one foot long. Wrap one end of each wire around a sewing needle just above the scraped part.

Attach the wires to a good six volt battery and put the bent ends into a beaker. Fill the beaker about three-fourths full of water and add a spoonful of sodium sulfate (Na_2SO_4) to the water. This will help the electric current to flow more easily through the water.

Look closely at the bent ends of the wire in the beaker. Describe what you see. What do you think the bubbles are made of? Remove one wire from the battery. What happens to the bubbles?

ACTIVITY

In this activity you will be able to catch the bubbles you saw coming from around the ends of the wires.

Fill a test tube with water. Put your finger over the opening and

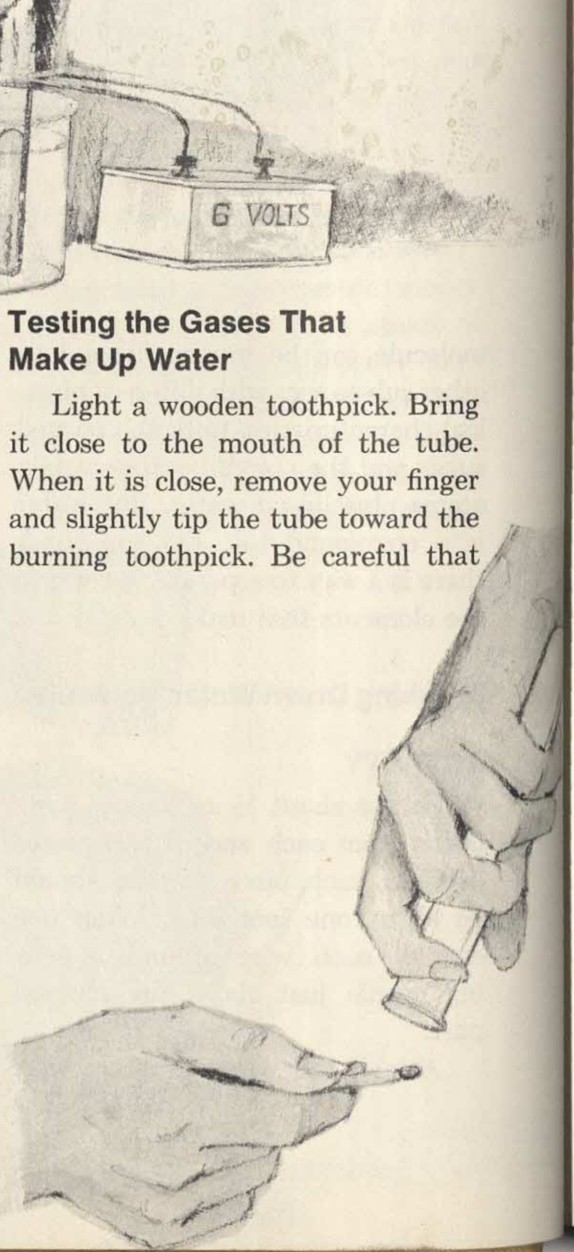
turn the tube upside down. Put the mouth of the test tube into the water in your beaker and remove your finger. Carefully move the test tube so that it rests over the bent end of one wire.

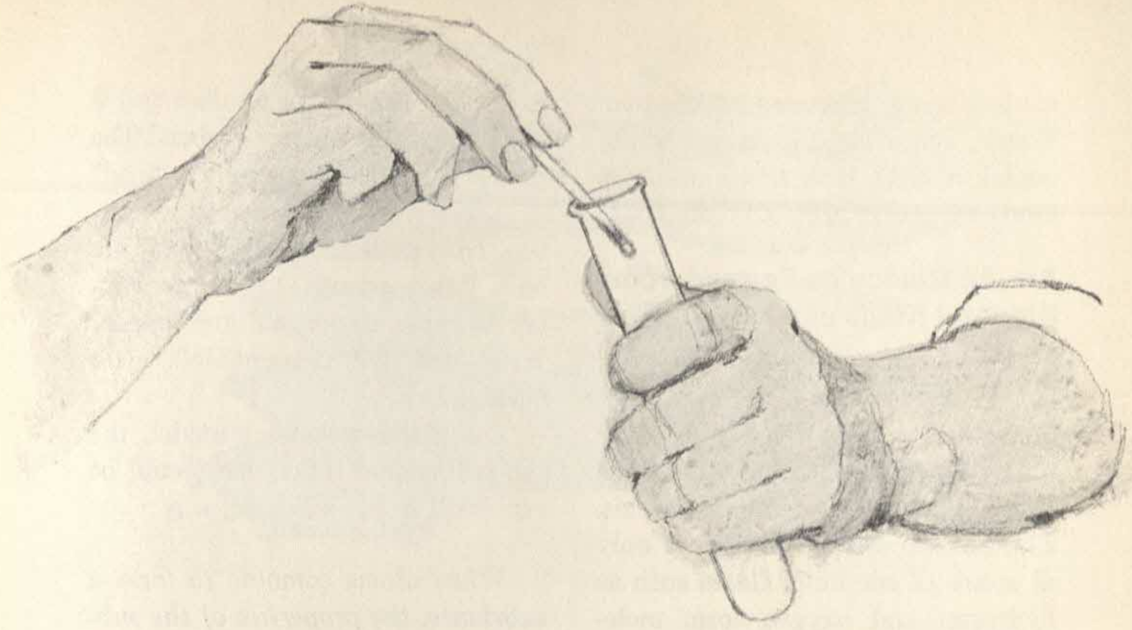
Fill another test tube with water and place it carefully over the other wire in the same way. Now attach the loose wire to the battery. What do you observe? Does one test tube seem to empty more quickly than the other?

Carefully lift the test tube which has had all its water pushed out by the gas. Put your finger over the mouth of the tube and lift it from the beaker. You now have a test tube filled with a gas. Keep the mouth of the test tube down. Can you tell what gas is in the test tube?

Testing the Gases That Make Up Water

Light a wooden toothpick. Bring it close to the mouth of the tube. When it is close, remove your finger and slightly tip the tube toward the burning toothpick. Be careful that





you do not drip water on the flame and put it out. Listen carefully as the flame comes closer. What do you hear?

Now when the second tube is filled with gas, turn the mouth of the tube upward after it is removed from the beaker. Light another toothpick. Blow it out and quickly place the glowing end into the mouth of the tube. What happens to the glowing end of the toothpick?

In the last two activities you separated water molecules into the elements which made them. Electricity flowing through the water caused the atoms making up the water molecules to separate. More hydrogen atoms bubbled from the water than oxygen atoms. Can you tell why?

Hydrogen is an explosive gas. A small bit of it can be identified by its explosion. Did you hear a "pop" when you brought a lighted match to the gas? Why do you suppose this is a good test for hydrogen?

Oxygen is also a gas which can be identified by the way in which it helps objects to burn. A glowing splint of wood brought near this gas will burst into flame.

You may wish to collect more hydrogen and oxygen to repeat the tests.

How do these activities show that water is not an element? When water is split apart with an electric current, it breaks down into the elements hydrogen and oxygen. Measurements have shown that the weight of water decreases as the two gases form. Would the weight of water get less if the water molecules were split apart? How would you account for a loss of weight in the water?

Water is considered a *compound*. This means that the smallest particle of water, the water molecule, is

made of more than one kind of atom. Water, according to our molecular model, is H_2O. How many different kinds of atoms are found in H_2O?

Are All Molecules Formed from Different Kinds of Atoms?

Carbon has been placed on your list of elements because it cannot be broken down further into other atoms. It is possible to find some single elements forming molecules. These molecules are made up only of atoms of one kind. Gases such as hydrogen and oxygen form molecules of this kind. Water, however, is made of molecules containing more than one element.

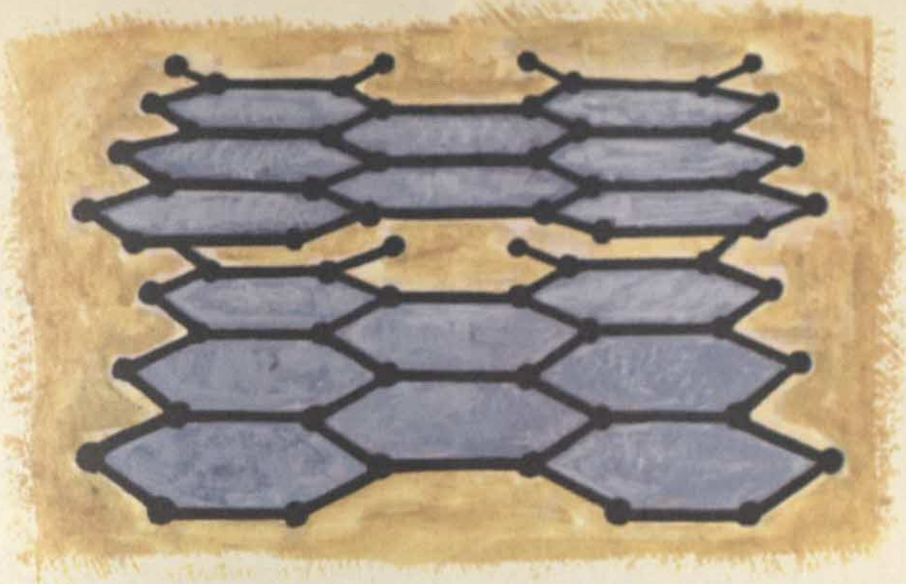
Did you know that a diamond is made up of the element carbon? The element found in your pencil "lead" is *graphite,* a different form of carbon. Diamonds and pencil "lead" are both pure carbon. Do you remember burning the sugar and paper? What was the element left after burning?

Using the molecular model, the similarities and differences could be explained in the following way:

When atoms combine to form a substance, the properties of the substance are determined by the arrangement of the atoms as well as by the kinds of atoms.

Diamond

Graphite



There are different ways in which atoms can join together. For example, the atoms that make up your pencil "lead" are all carbon atoms. The "lead" in your pencil is misnamed, because it is not lead at all; it is a substance called graphite. What test would show that graphite is made of carbon?

ACTIVITY

Take 4 middle sized polyfoam balls and attach them together with wires to form a model of graphite.

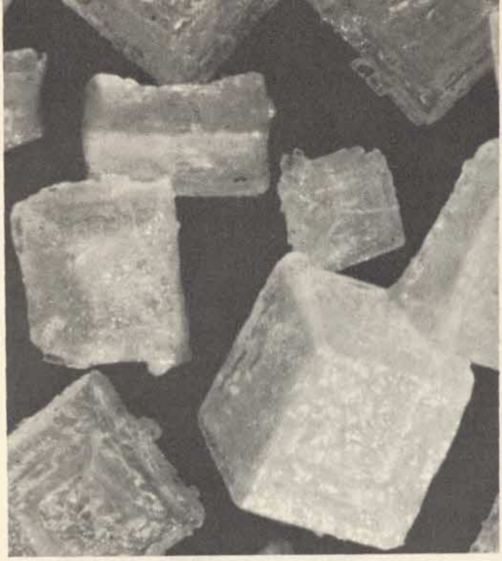
Make several more models of this structure.

Molecules, as well as atoms, arrange themselves in different ways. In graphite, each carbon atom has three other carbon atoms attached to it. When the carbon atoms join this way, the arrangement is such that each atom still has 3 other atoms attached to it. Arrange your carbon atoms as shown above.

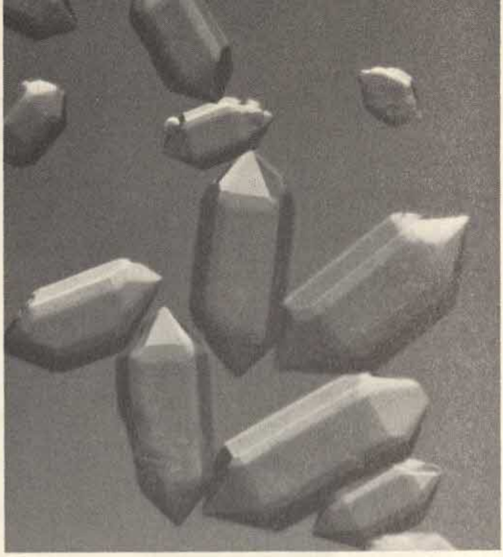
As the carbon atoms join together, they form six sided figures. It takes many millions of these figures to form a small piece of graphite. Obtain some graphite from a hardware store. Describe it. Put a tiny amount of it on your finger. Rub your fingers together. How does graphite feel? You have learned some of the properties of graphite. How do you think people have made use of these properties? Does the structure of graphite explain why it is slippery? □□

OBSERVE

Look at a small grain of salt under a magnifying glass or microscope. Describe its shape. How do several grains feel? How are the properties of salt different from those of graphite? One Na atom and one Cl atom are joined side by side to form one tiny piece of salt. When several of these pieces join together, they continue to join side by side,



Rock Salt



Quartz

up and down, in front and in back of each other. What shape do these atoms begin to form? If more and more Na and Cl join onto this shape, the shape would appear to grow larger and the larger shape would remain the same. Does this shape look similar to the grain of salt you observed? □□

The shape of a substance tells scientists much about how the atoms are joined together. Many substances have shapes which help to identify them. If the shapes have smooth flat sides, sharp edges and pointed corners, we call them *crystals*. In the case of salt, one piece of NaCl should really be called a crystal. It is important to know that when a crystal is broken, it will only break in certain ways, and the smaller pieces will still resemble the original shape. It is possible to predict how a crystal will look after you break it.

Crystals

Obtain some samples of crystals such as Epsom salts, or rock salt, and look at them carefully under a magnifying glass. Do both of these substances have flat sides, sharp edges, and pointed corners? When you break these crystals into smaller pieces, what happens to their shapes?

Is glass a crystal? Does it have flat sides? Does it have sharp edges? Does it have pointed corners? Can you break it only in a certain way? Can you predict how glass will look after you break it? Is glass *really* a crystal?

Solutions and Crystals Growing

When crystals of the same kind break, they always break in a way common to that type of crystal. It is also true that when they are formed, crystals always arrange themselves in a regular pattern. You can see this by growing your own crystals.

Picture of a Tungsten Crystal Magnified over 2,000,000 Times

INVESTIGATE

Fill each of four beakers with a cup of water. Put one level spoonful of sugar in the first beaker, the same amount of salt in the second, the same amount of dirt in the third, and the same amount of cooking oil in the fourth. Use a separate spoon for stirring each beaker. What do you observe? Do all substances dissolve in water?

A substance that dissolves is called a *solute.* Which substances in this activity are solutes? Do you know any other solutes?

A liquid that dissolves a substance is called a *solvent.* Is water a solvent? Is gasoline a solvent? Does your mother have any cleaning solvents at home? How do they work?

When a solute dissolves in a solvent, a *solution* is made. In the first beaker you have a solution of sugar and water. What do you have in the second beaker? Are beakers 3 and 4 filled with solutions?

Set aside beakers 3 and 4. In beaker 1 you have a spoonful of sugar in a cup of water. In beaker 2 you have the same amount of salt in a cup of water. Both are solutions. Could more sugar and salt be added to the solutions?

Add 10 more spoonsful of sugar into the sugar solution. Stir the solution. Now add the same amount of salt into the salt solution. Stir. Observe the containers. Are they still clear? Does some of the sugar or salt remain on the bottom of the beakers?

How many more spoons of sugar and salt will the solutions hold? Find out by adding one spoonful of solute at a time to the beakers. Stir after each addition and observe. Keep a record of your observations.

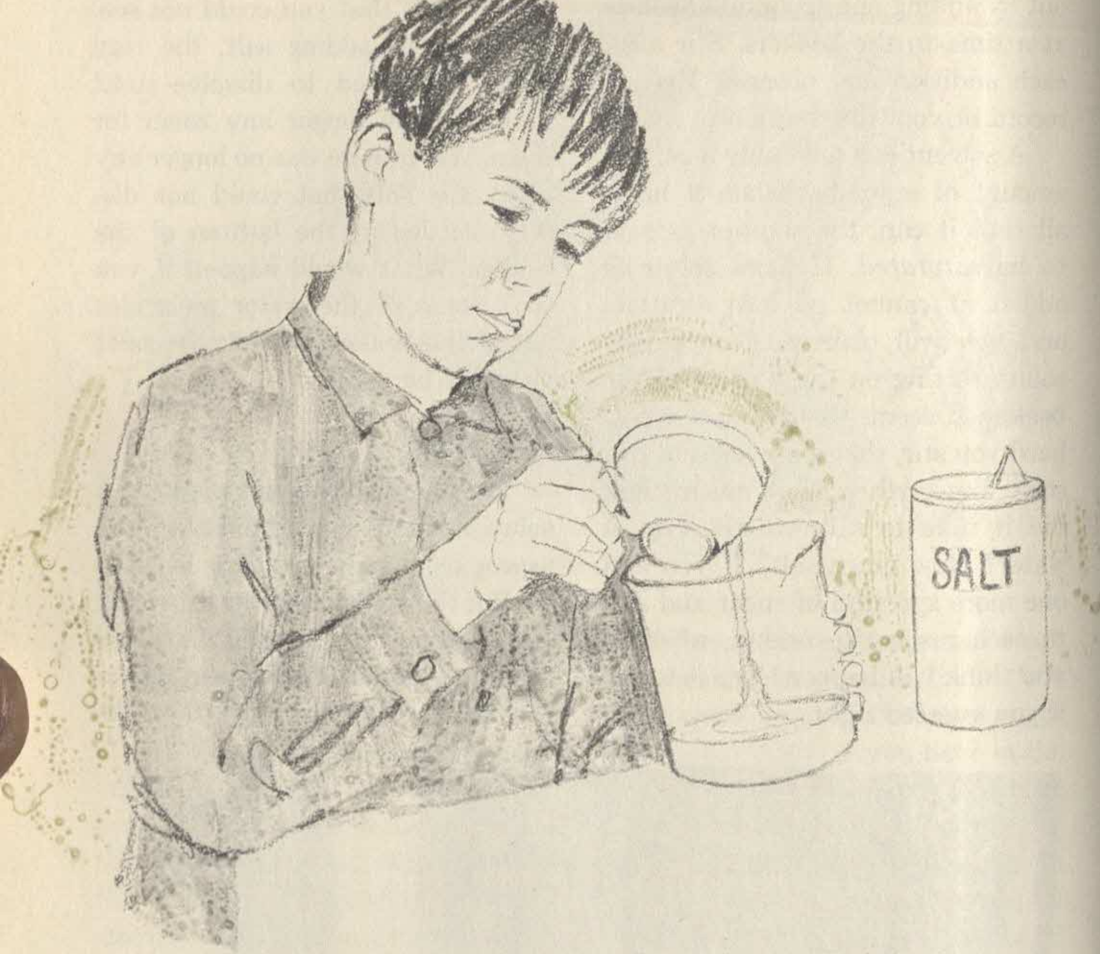
A solvent can hold only a certain amount of a solute. When it holds all that it can, the solution is said to be *saturated*. If more solute is added, it cannot go into solution, and you will observe some of the solute resting on the bottom of the beaker. It seems that no matter how hard you stir, the solute will not dissolve any further. How much sugar did it take to saturate the cup of water? How much salt? If you add one more spoonful of sugar and salt to each respective beaker, what do you think will happen? Try it to see if you guessed right.

When you put the salt into the water, the salt divided into very small pieces that you could not see. As you kept adding salt, the tiny pieces continued to dissolve until there was no longer any room for them. When there was no longer any room, the salt that could not dissolve settled at the bottom of the beaker. What would happen if you took some of the water molecules out of the beaker, but left the salt? Can this be done?

OBSERVE

Pour a small amount of the salt solution into a saucer and place the saucer on a sunny window ledge.

Put the beaker with its saturated salt solution on a heating unit until the solution boils. As the heat makes the water evaporate, will there be



as much room in the solution for the salt? What will happen to it? Observe the heated beaker as the water evaporates. Turn off the heat and let the solution cool. What do you observe after the solution has cooled? Can you explain what you see?

Look at the saucer of salt solution each day until the water has completely evaporated. What makes the water molecules evaporate? Does the salt evaporate? How do you know?

Do you notice any difference in the appearance of the salt in the

saucer when compared with the salt in the beaker?

Repeat this same activity with your solution of sugar. Do you get the same results?

Did you find that it took more spoons of sugar than salt to saturate a cup of water? It takes different amounts of different substances to saturate a solution. Is it possible to put even more of a substance into solution? Let us change the condition of the solution to find out.

ACTIVITY

Put a half cup of water in a beaker. Saturate the water with sugar. How can you tell when you have a saturated solution?

Place the beaker on a heating unit and heat it slowly. Do not allow the solution to boil. What happens to the sugar that was at the bottom of the beaker? Add another spoonful of sugar to the solution and stir. What happens? Add another spoonful. Stir. Does it rest on the bottom? How many more spoons of sugar can you add? Does heat make it possible for a solution to hold more solute?

What do you think would happen if you took the beaker off the heating unit and let it cool? Find out. What do you observe? Why did it happen?

Can you dissolve more salt in a salt solution when the solution is heated? How much more?

In the last few activities you have set up conditions that help in growing crystals. You have probably observed some small crystals in the beakers and saucers. Growing larger crystals requires a few additional steps.

ACTIVITY

You will need another salt solution. Fill a beaker with 2 cups of water. Heat the water until it boils, and add salt to the water until it is saturated. Can you see the solute in the solvent? How do you know it is there? Allow the solution to cool.

When the solution has cooled, do you see any salt crystals at the

bottom of the beaker? Is there still any salt in the water? Is the solution saturated? Keep the solution until crystals form.

After some crystals have formed, pour the saturated solution through a piece of cloth (folded over several times) into several small jars. What purpose does the piece of cloth serve? Save the crystals and look at them through a magnifying glass.

Select several of the largest of these crystals and let them sit on the bottom of the beaker containing a saturated salt solution. Observe them several days later. Are they larger? Again strain the solution through the folded cloth and remove the larger crystals. Repeat this procedure until the largest crystals are big enough to tie a piece of thread around. Do this and suspend the crystal in another saturated solution

of salt. The tied crystal provides a base upon which other crystals will grow.

Look at the new crystals after several days. Has the size changed? Observe the beakers each day. What is happening to the salt crystals? Do they form in an organized way?

After several days you may see that some threads have only one large crystal on them. Others may have clusters of many little crystals. The salt crystals form around tiny particles in the solution. Some threads may have had many small particles on them. As a result, many small crystals were formed.

Remove the crystals from the solution and look at them under a magnifying glass. What shape are they? What color are they? Do they have flat sides, sharp edges, and pointed corners? Have you ever seen rock salt? Can you tell how it was formed?

Crystals can be grown from many other substances such as Rochelle salt, photographic hypo, and Epsom salts. Many of these substances can be obtained at a local drug store.

Try to grow some crystals from these substances. Compare the crystals. Are they all the same shape and color? Do you know why are they different?

In growing crystals the atoms seem to form orderly patterns to build the definite shapes of the crystals. Do the crystals shown at the right support this statement?

Sugar

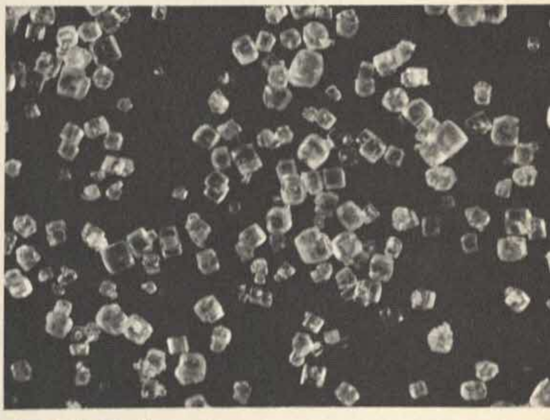
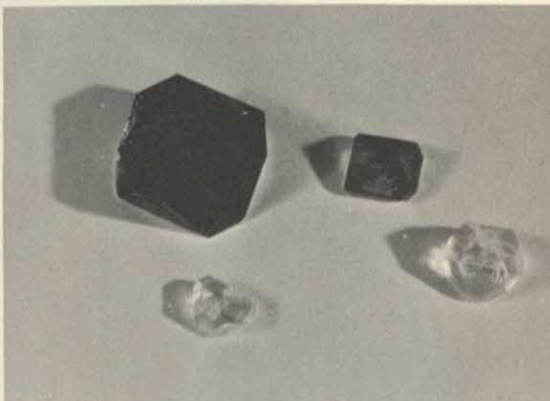


Table Salt



Alum

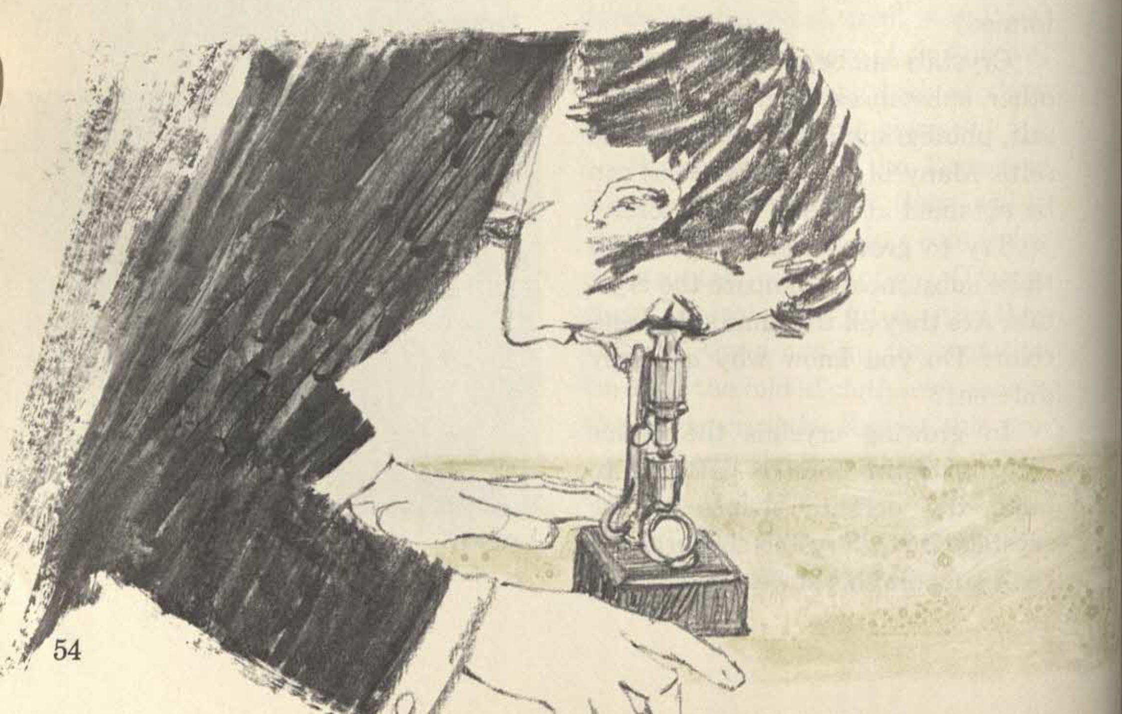
Robert Brown

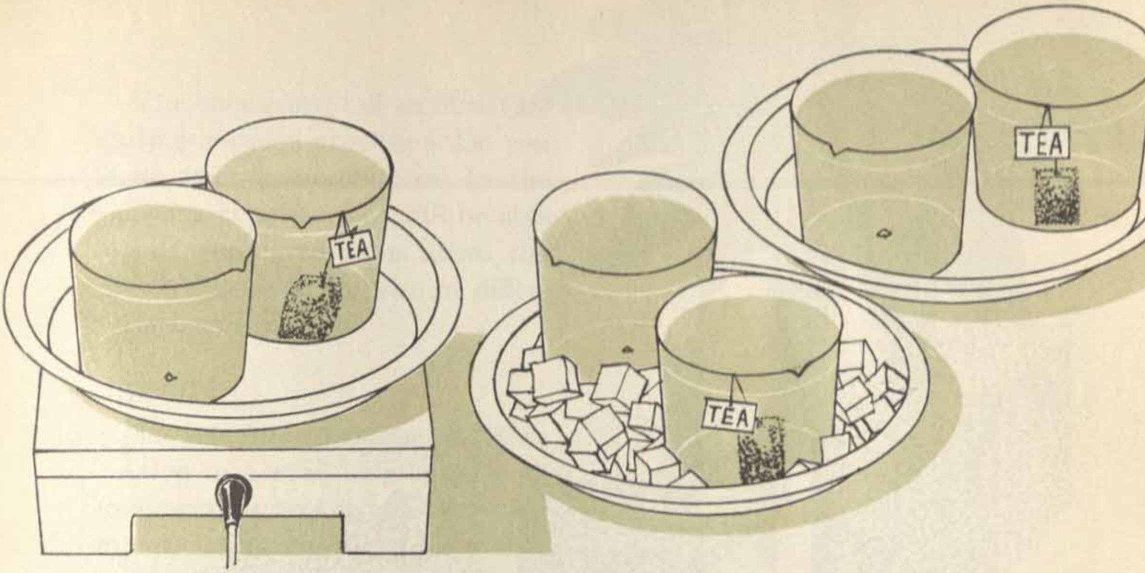
The Motion of Molecules

In 1827, Robert Brown, a Scottish botanist, made observations which provided evidence that atoms and molecules are always in motion. While examining tiny grains of pollen placed in a liquid under his microscope, Brown noticed that the pollen grains danced about with a zigzag motion. It is now believed that these pollen grains were being pushed about by the invisible moving molecules of the liquid. It is also believed that the molecules in solids, liquids, and gases might be bouncing against other molecules in a random fashion. The bouncing can be compared to the way in which marbles would move if you shook a large group of them together in a box. The movement of the pollen grains was named after the discoverer and is now called *Brownian motion.*

ACTIVITY

Fill a beaker with water. Onto the surface of the water, place a drop of ink. Observe what happens to the ink molecules. How do you think they are able to spread throughout the whole beaker of water?





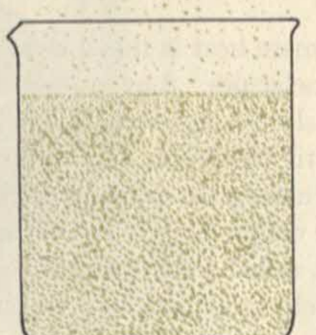
COMPARE

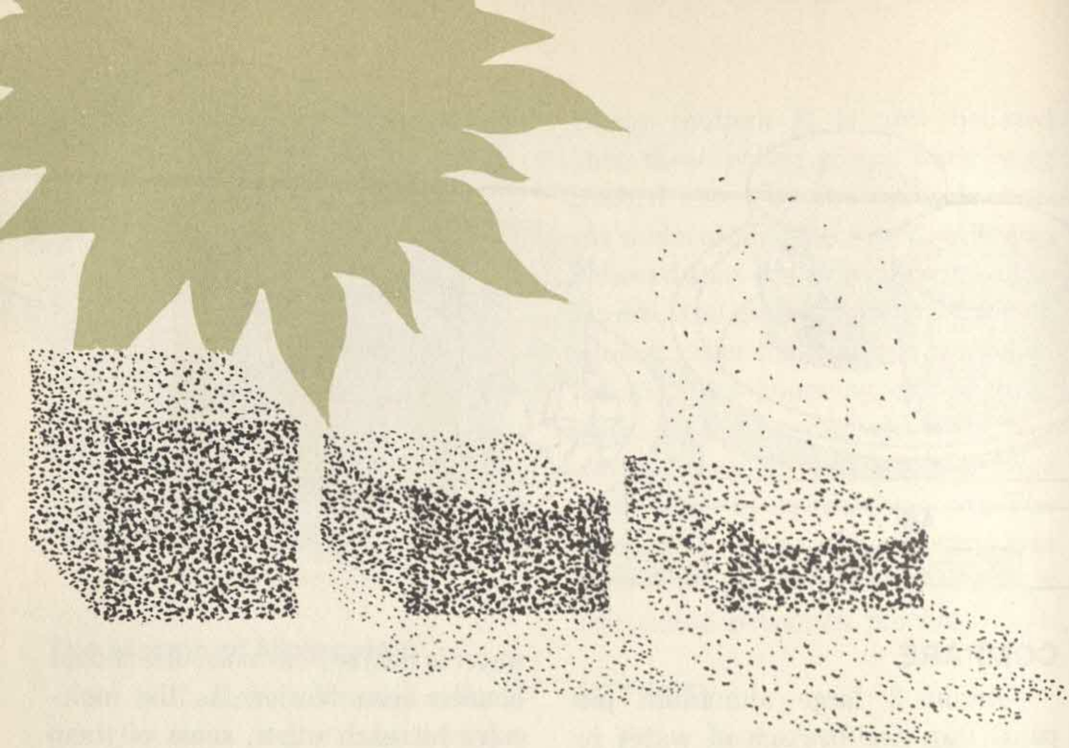
Obtain 3 large aluminum pie pans. Put two beakers of water in each pan. In one of the two beakers in each pan, place a copper sulfate crystal. Into the other beaker in each pan, hang a tea bag.

Place one pie pan on a heating unit, and turn the heat on very low. Let one pan remain on a table at room temperature. Around the two beakers in the third pan, pack as many ice cubes as you can.

Observe each of the beakers. Do you think the temperature has anything to do with the motion of the particles in the solution? □□

If the speed of molecules increases, the molecules should bump into each other with more force. When they do this, they should knock each other farther apart. If you could imagine the molecules in a glass of water, you might be able to picture the molecules bouncing against each other. If the glass of water is heated, the molecules should bounce even harder. As the molecules hit each other, some of them might strike with such force that they would bounce right out of the glass into the air. When the molecules are very far apart, scientists say that the substance is a gas. How does this model help to explain evaporation?





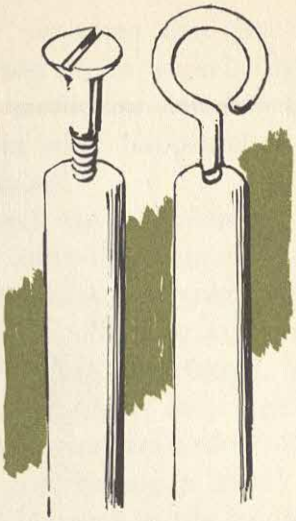
If some heat is taken away from a substance, the molecules would slow down and would not hit each other with as much force. The molecules would be closer together and would move more slowly. A substance with molecules moving in this way is called a liquid. How does this idea help to explain the moisture that appears on the side of an iced drink?

If more heat is taken away from the molecules, they would move more slowly and strike each other with still less force. As a result they would also be closer together. A substance with molecules moving in this way is called a solid. How does this idea help to explain the presence of solid wax at the base of a burning candle?

Although liquids can change to solids when heat is removed, the molecules would still be in motion. Even in ice, the molecules would still be moving. Scientists, as yet, have not been able to show that molecules can be stopped from moving altogether; and although they have come very close to stopping molecular motion, at temperatures hundreds of degrees below zero, they have not yet succeeded.

If heated molecules have more space among them, what might happen to a substance when it is heated? Do you think it might get larger? Using the model of molecules, can you predict what might happen to a substance if it is cooled? Do you think solids, liquids, and gases would all behave the same way?

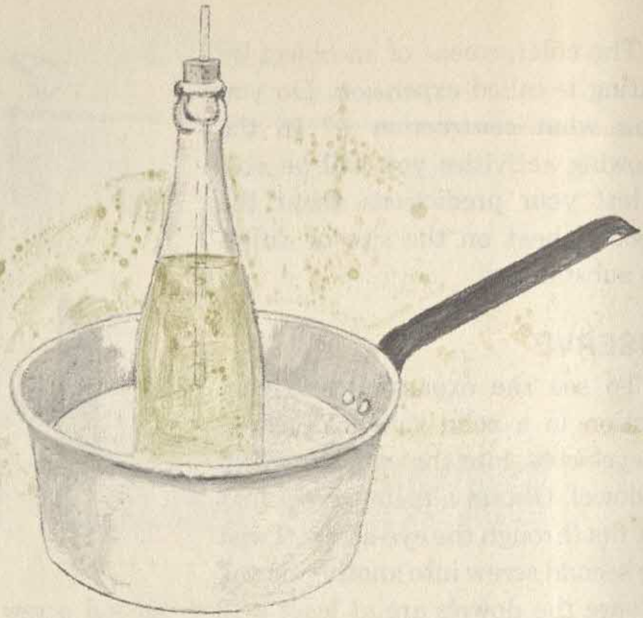
The enlargement of an object by heating is called *expansion*. Do you know what *contraction* is? In the following activities you will be able to test your predictions about the effect of heat on the size of different substances.



OBSERVE

To see the expansion and contraction in a solid substance, twist an eye-screw into the end of a wooden dowel. Obtain a metal screw that just fits through the eye-screw. Twist this second screw into another dowel. Be sure the dowels are at least 8-12 inches long.

Pass the second screw through the eye-screw to make sure it just barely passes through. Now heat the second screw in a flame for several minutes and then try to pass it through the eye-screw again. What happens? What happened to the molecules in the heated screw? Heat



the eye-screw. Does the screw pass through the eye-screw now? Why? Let the objects cool. What happens when you try it again?

When the eye-screw and the screw are again at room temperature, place the eye-screw into a very cold solution of ice water and salt. Again try to pass the screw through the eye-screw. What happens? How do changes in temperature affect the solid eye-screw and screw? When do solids expand? When do they contract?

ACTIVITY

To see expansion and contraction in a liquid, fill two bottles with water that has been colored with a food coloring. Use enough food coloring to deeply color the water. Make sure that each bottle is filled right to the top. Now insert a glass tube through each of two 1-hole stoppers. When you put the stoppers into the bottles, make sure that there are no air bubbles inside. Mark the height of the liquid in each tube. Place one of the bottles into a pan of water and heat the pan slowly. Does the height of the water in the tube change? In which direction? Does this support what you know about the behavior of molecules when they are heated?

Now place the other bottle in a pan and cool it by packing ice around the bottle. What happens to the height of the water in the tube? Can you explain the effect the cooling had on the water molecules? Might they take up less space?

PREDICT

To see expansion and contraction in a gas, cut off the necks of two balloons. Stretch the cut edges of the balloons over two jars and attach them with rubber bands as shown in the illustration. What is inside each jar?

Place one of the jars in a pan of water and heat the pan slowly, as in the last activity. What happens to the stretched balloon? What causes this change?

Can you predict what will happen to the stretched balloon on the other jar when that jar is placed in a pan of ice water? Try it. Was your prediction correct? Can you explain what happened to the gas molecules? □□

Heat causes molecules to move faster and bounce against each other. Do you think that your model of the molecule will allow you to predict how heat is transferred from one part of an object to another?

Have you ever cooked something in a pan having a metal handle? What happens to the handle of the pan after the pan has been over the

flame for a while? How does a molecular model help to explain the movement of the heat?

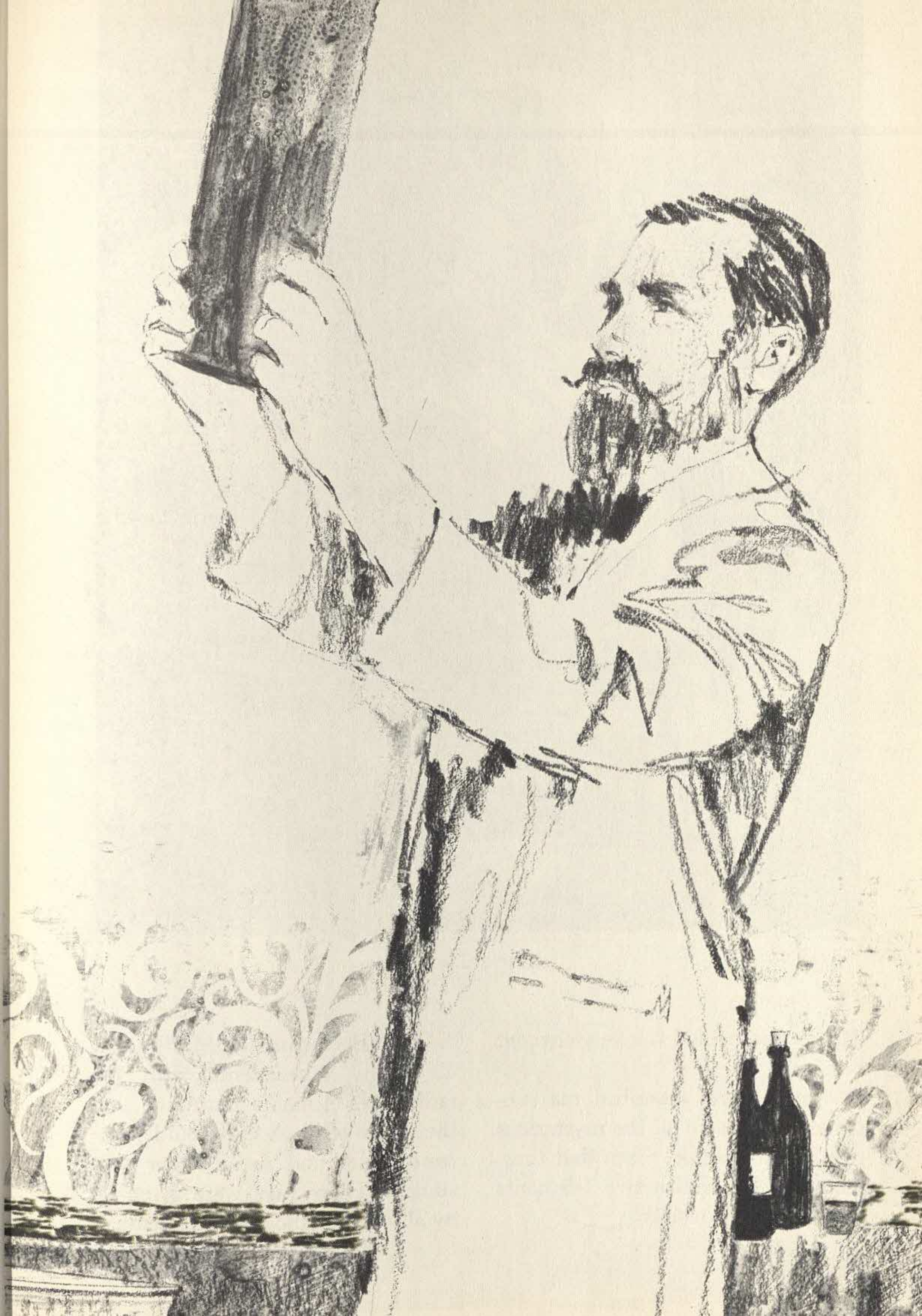
ACTIVITY

Obtain a brass curtain rod or other long piece of metal. Attach several tacks to it with drops of candle wax. Place the tacks about two inches apart. Now hold the rod in a level position with one end in a flame. When do the tacks fall off the rod? Do they all fall off the rod at the same time? What does this activity indicate about moving molecules? □□

Radioactivity

After the early work of John Dalton and other scientists which lead to the models of the atom and molecule that you have studied, a Frenchman, Henri Becquerel, made another important discovery. In 1898 he was experimenting with element number 92, uranium, and found that if a photographic plate were left near uranium in a dark room, the uranium would make a picture on the plate. It would do this even if a black sheet of paper were put between the photographic plate and the uranium. Becquerel thought that the element uranium was giving off rays that could pass through the black paper and affect the photographic plate. He wondered how uranium could do this while the other known elements could not.

While experimenting with the element uranium, Marie Curie, and her husband Pierre, discovered another element that gave off more powerful rays of the same type.



Marie Curie

The Curies named the new element radium.

Marie Curie described the substances that gave off the mysterious rays as *radioactive*. Since that time, many more radioactive elements have been discovered.

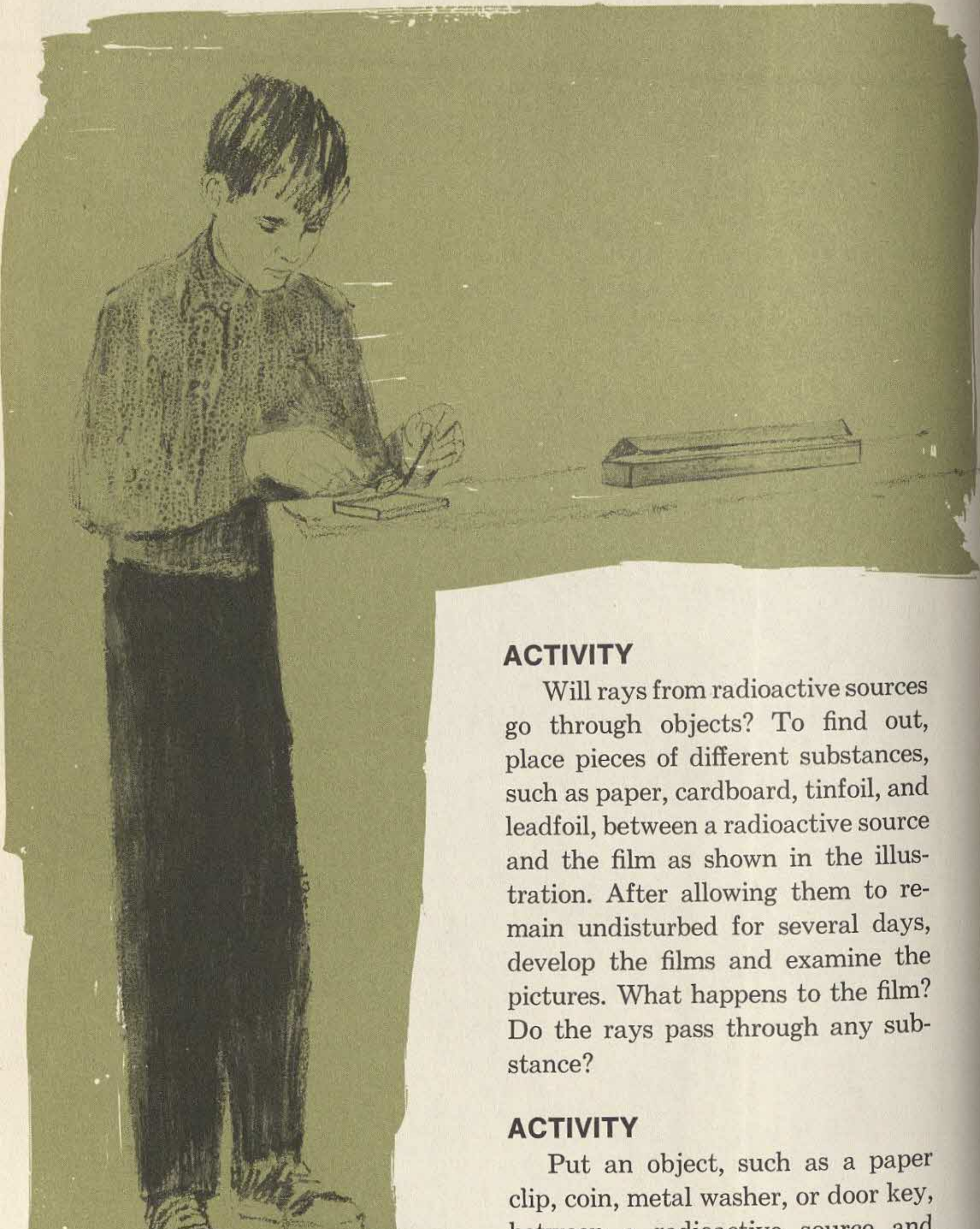
Both Becquerel and Marie Curie did many experiments with the radioactive elements and found that they gave off rays that could penetrate paper and many other substances. These rays were given off by all of the radioactive elements.

ACTIVITY

Many wrist watches have radioactive materials on them. These materials are used to help you see the numbers and hands of the watch in the dark. Obtain a small film packet from a photographic shop. Let a radioactive watch run down, so that the hands are no longer moving.

Put the watch face down on the photographic film in a dark room or inside a lightproof box. Be sure to follow the directions on the film in order to have the right side of the film next to the watch face.

Do not disturb the film or the watch for at least two days. Then remove the watch, wrap the film, and have it developed. Examine the picture carefully. What do you notice about the film? You have just done an experiment similar to the one that Becquerel did in 1896. How does light affect photographic film? How does a radioactive substance affect photographic film?

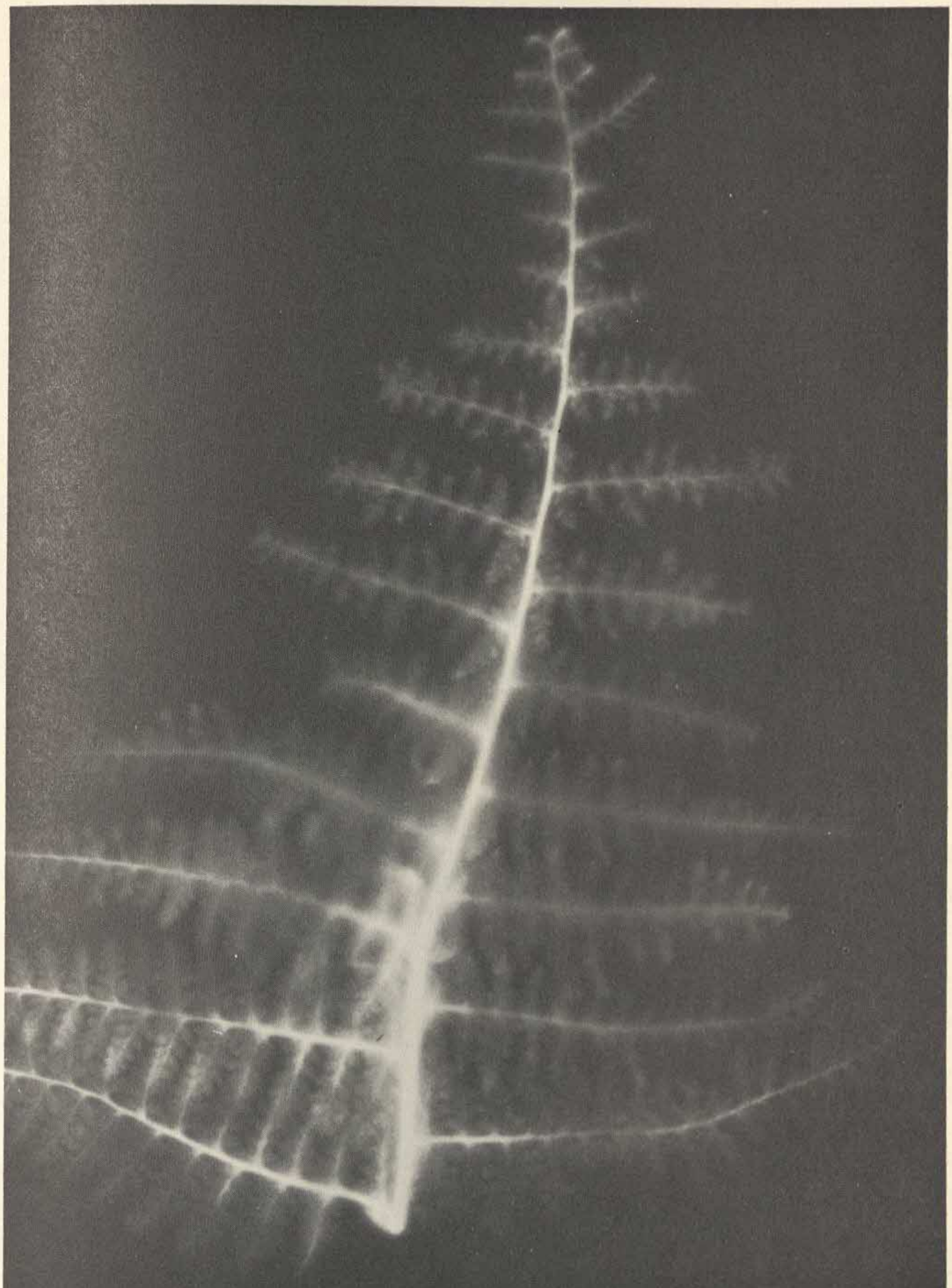


ACTIVITY

Will rays from radioactive sources go through objects? To find out, place pieces of different substances, such as paper, cardboard, tinfoil, and leadfoil, between a radioactive source and the film as shown in the illustration. After allowing them to remain undisturbed for several days, develop the films and examine the pictures. What happens to the film? Do the rays pass through any substance?

ACTIVITY

Put an object, such as a paper clip, coin, metal washer, or door key, between a radioactive source and some photographic film for several days. What kind of a picture do you get? Why? □□

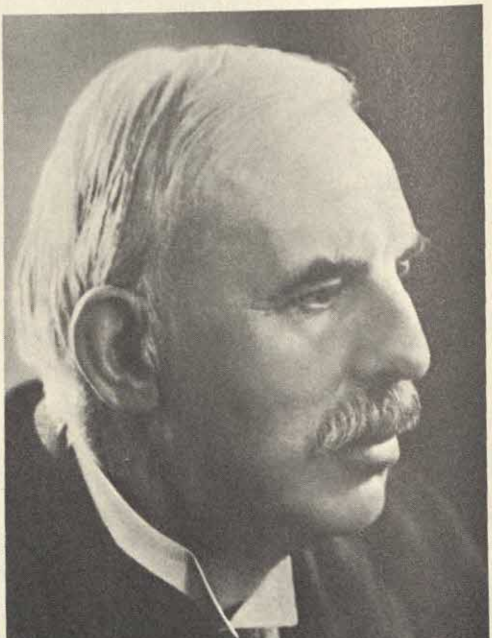


What was the source of light for this photograph?

Some students may have samples of radioactive uranium in their rock collections. Try setting some radioactive ore samples next to photographic packets for several days. What kinds of pictures do the various ores make? Did invisible rays make the pictures? Where did the rays come from?

Further Improvement of the Model

Ernest Rutherford in England used the newly discovered rays to explore the atoms in gold. In 1911, he allowed a beam of the new rays to pass through a thin sheet of gold with photographic paper behind it. Some of the rays passed through the



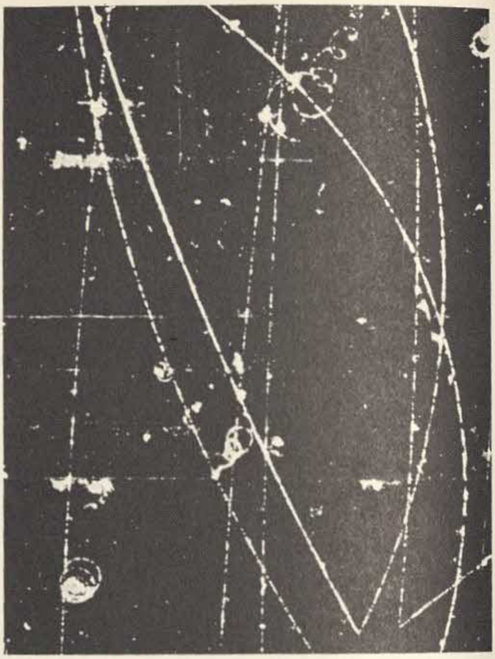
Ernest Rutherford

metal as a bullet would pass through the leaves on a tree. But some of the rays scattered about, and some bounced right back. This experiment suggested to Rutherford that atoms are not solid, but that there must be space in them to allow some rays to pass through. The rays that scattered and bounced back, he felt, must have hit a hard solid core in the middle of the atom. From this reasoning he developed the idea that the protons in an atom are crowded together in the center core, and the electrons are located around the center. He named the core of an atom the *nucleus*. This helped scientists to improve their model of the atom. Do you remember your static electricity experiments? How does this model compare with the model suggested to explain static electricity?

The Cloud Chamber

To try to photograph the parts of an atom, Charles Wilson invented a cloud chamber in which he could make a fog. To do this he had to know that warm air holds more

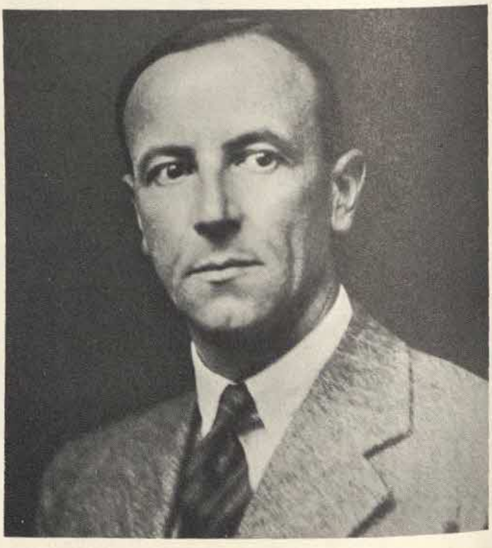
Trails made by jet aircraft



Trails made by atomic particles

moisture than cold air. He also had to know that when the warm air is cooled suddenly, a fog forms. He fixed the chamber so that atomic rays could pass through it. When the rays passed through the fog, a trail could be seen and photographed. The trail looked somewhat like the trail made by a jet aircraft in the sky. He found that the different rays could be identified by the trails they made. The rays seemed to behave like tiny particles.

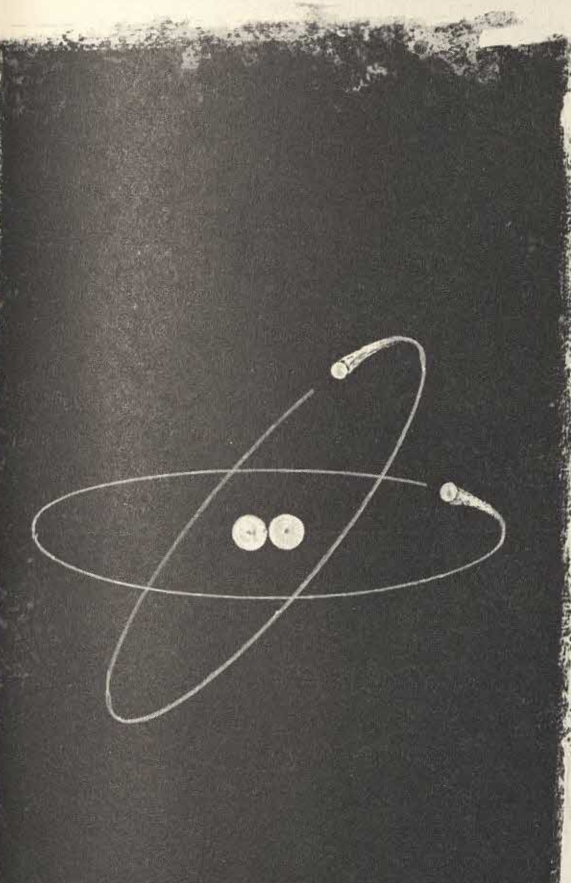
To solve the problem about the different weights of atoms, James Chadwick studied the parts of boron atoms in a Wilson cloud chamber. He found the trails of negative electrons and positive protons. He also found the trail of a new particle which was not positive or negative but which was about the same size and weight as the proton. It was thought that this new particle was

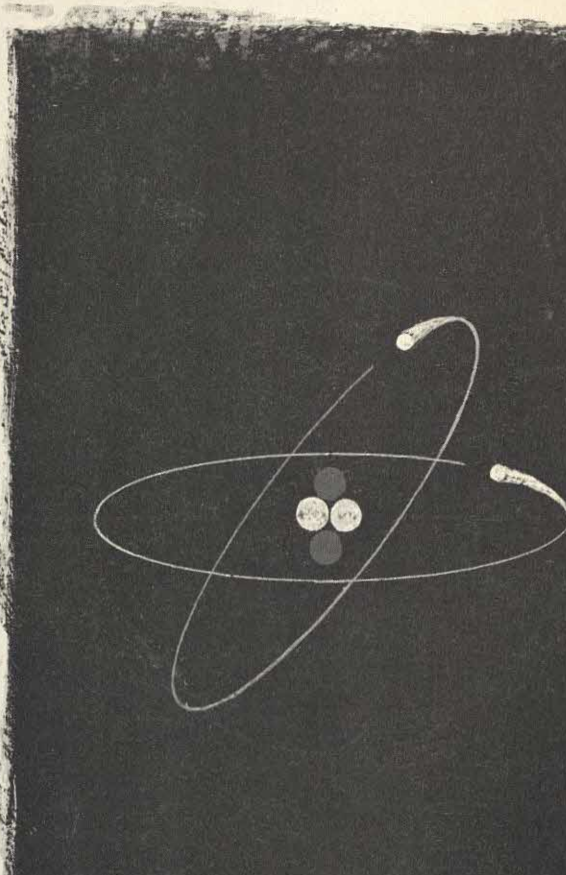


James Chadwick

also a part of atoms, and, since it was electrically neutral, being neither positive nor negative, it was called a *neutron*. The neutron answered the problem about the weights of atoms and changed the imaginary model again.

Why was it that hydrogen with its 1 proton and 1 electron weighed 1 unit, while the next element, helium with its 2 protons and 2 electrons, weighed 4 units? It was believed that most of an atom's bulk (mass) was centered in the proton. The electron has almost no mass. Helium, according to the model, should weigh 2 units, not 4. After the discovery of the neutron, scientists felt that the helium nucleus had to contain 2 protons and 2 neutrons. This seemed to be the best explanation for helium's weight of 4 units. Could there be a heavy form of hydrogen? What would it weigh?





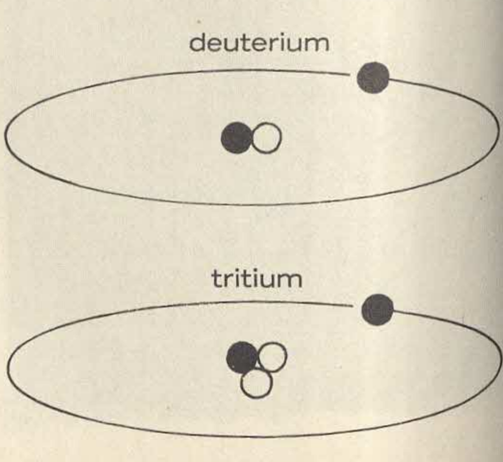
Harold Urey

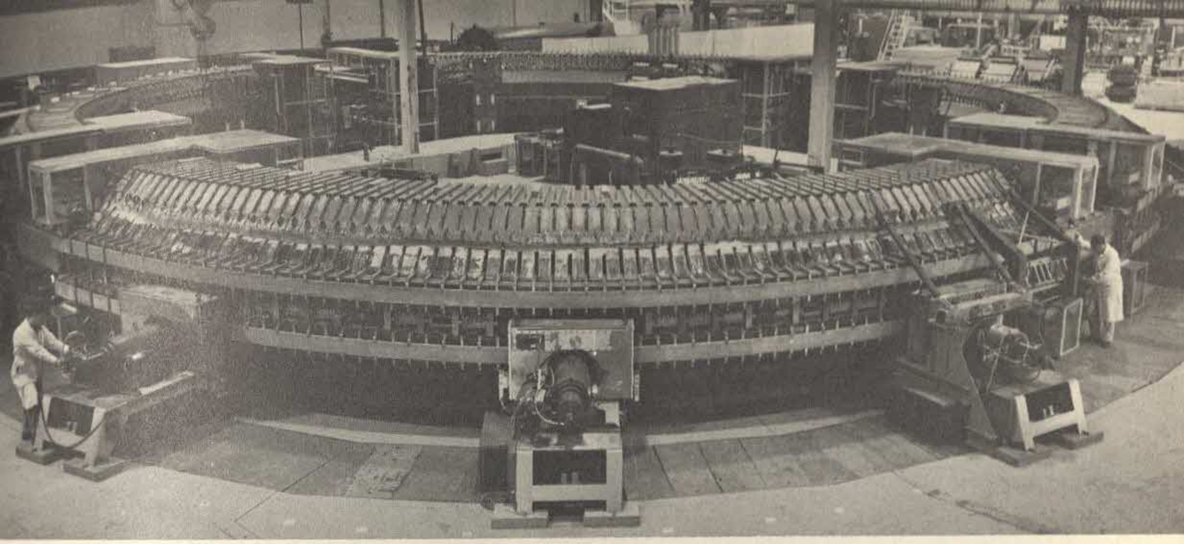
In 1932, Harold Urey, an American scientist discovered heavy hydrogen. The extra mass of the atom was due to a single extra particle, the neutron. This form of hydrogen was named *deuterium*. Later, a second form of heavy hydrogen was discovered having one proton, one electron and *two* neutrons. It had a mass of 3 and was named *tritium*.

Now scientists had a much more useful model of atoms. Atoms were composed of protons, electrons and particles weighing as much as protons, called neutrons. In this way an explanation could be given for all the actual weights of all of the elements; and for the first time, elements having similar properties but different weights could be explained. There were still only 92 natural elements, but each natural element could exist in different forms that varied slightly in weight. These elements having the same properties but having different weights were given the name *isotopes*. Isotopes of an element have the same number of protons, but have different numbers of neutrons.

In 1895, just before Becquerel started his experiments with radioactive materials, a German physicist made another startling discovery. His name was Wilhelm Roentgen (RENT-gun) and he discovered X rays. These rays were called X rays because Roentgen did not know what they were. The X rays, discovered and named by Roentgen, are the same kind of rays used in making medical examinations.

These rays are very much like the rays given off by radioactive elements. Their discovery led to a great deal of experimentation that eventually led to the atomic age.

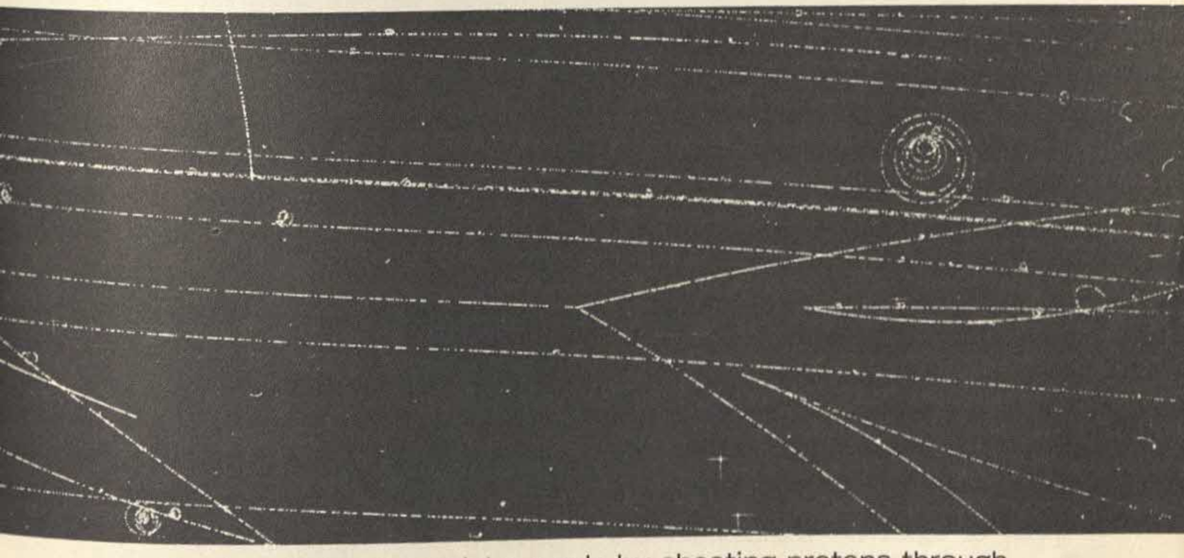




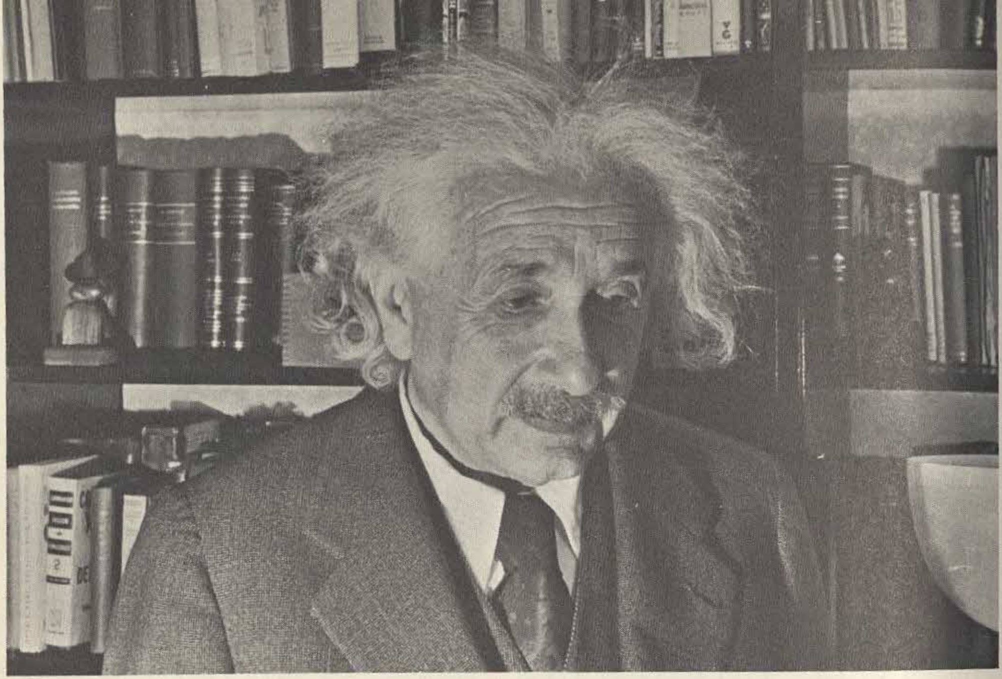
The Cosmotron—A Giant Atom Smashing Machine

Atom Smashing

Scientists can "shoot" atomic particles at the nucleus of atoms to knock it apart. This is done in order to study the nuclear pieces and the forces that hold these pieces together. They have built special machines to shoot the particles at great speeds, and they have constructed devices to get pictures of the results. By now scientists have found many different particles that make up the atom. The following picture shows the trails made by the various parts of atoms after they have been hit by speeding atomic particles.



Tracks of atomic particles made by shooting protons through liquid hydrogen

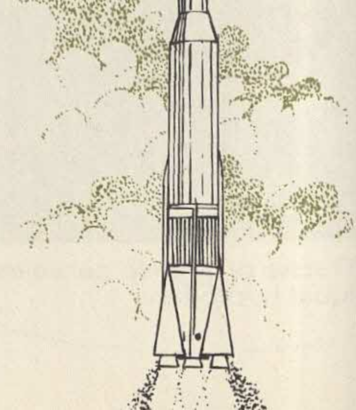


Albert Einstein

Scientists still do not understand what holds the many particles together in the nucleus, but whatever it is, it has a great amount of energy. When this energy is released, it is called *atomic energy.*

In 1905 Albert Einstein predicted a relationship between matter and energy. He said that the amount of matter (mass) and energy are two forms of the same thing. He predicted that if an amount of matter of mass M were destroyed, then an amount of energy E would be released in proportion to the mass.

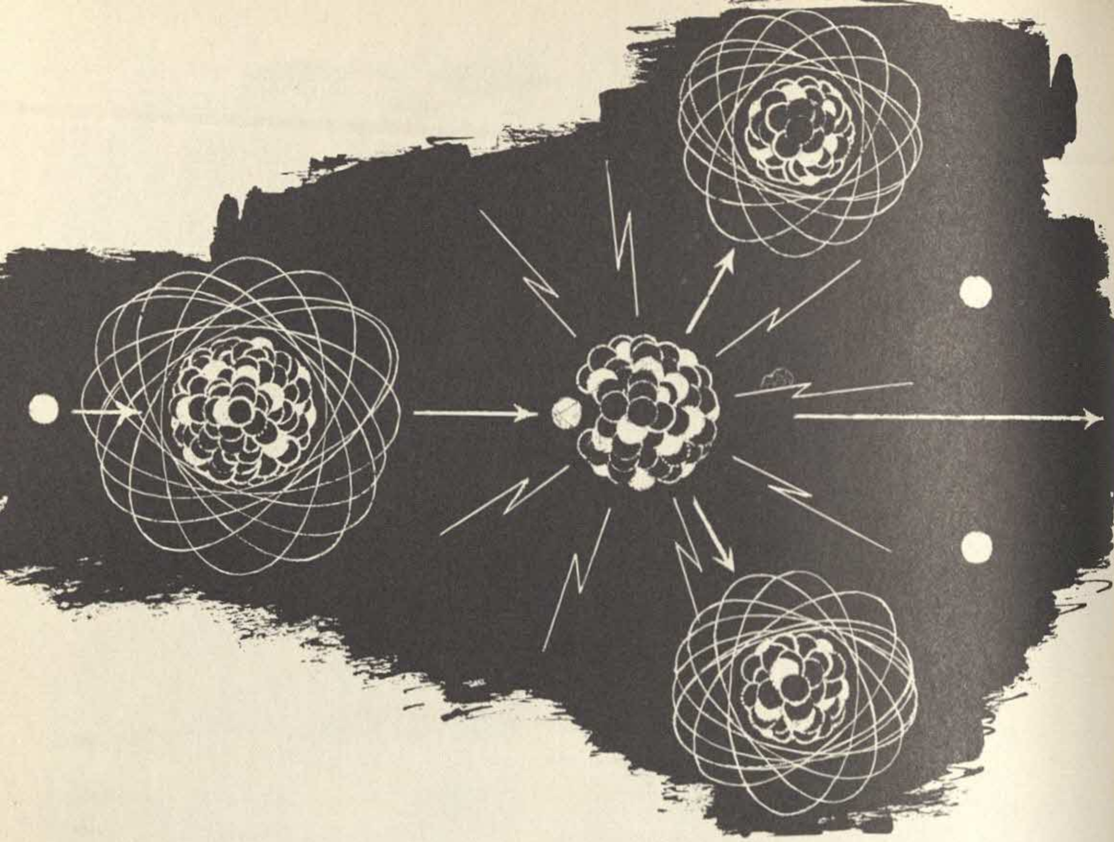
Einstein wrote his relation as: $E = MC^2$. E stands for the amount of energy released. M stands for the amount of mass lost. C stands for the speed of light. C^2 means that the speed of light must be multiplied by itself, or squared. (MC^2 stands for M multiplied by the speed of light squared). The speed of light is exceedingly great. It is 186,000 miles per second. Therefore, the speed of light squared is a very large number indeed. You can see that the energy



The atomic bomb releases the energy in matter.

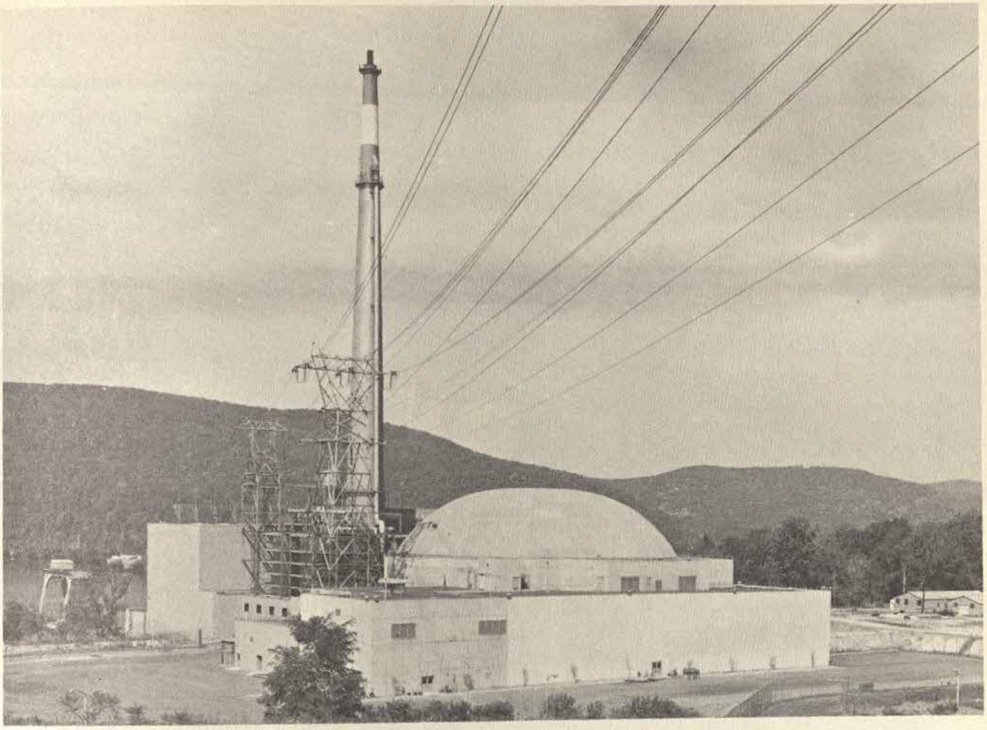
released from just a tiny bit of matter will be very great. An amount of matter about the size of a garden pea contains enough energy to lift a 6 million ton rocket one mile into the sky. It has been estimated that if 10 pounds of matter could be completely destroyed, the energy released would supply enough electric power for the entire world for one month.

The atomic bomb releases energy in the way that Einstein predicted. When the inside parts (nuclei) of uranium-235 atoms are split in an atomic bomb, they each become two nuclei of lighter elements. It is observed that the two lighter nuclei together weigh less (have less mass) than the original uranium nucleus. Therefore, in the splitting process a small amount of mass has been lost or destroyed. Although the mass lost is very small, this nevertheless is the basis for the tremendous release of energy of the atomic bomb.

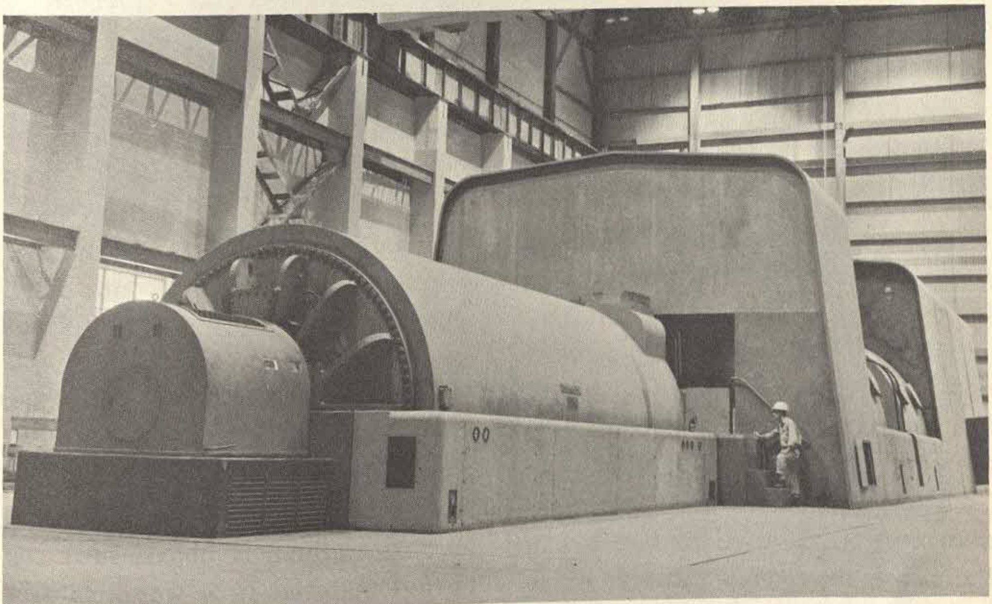


Uranium 235 has 92 protons in each nucleus. That is why uranium has the atomic number 92. Do you know how many neutrons each uranium-235 nucleus contains?

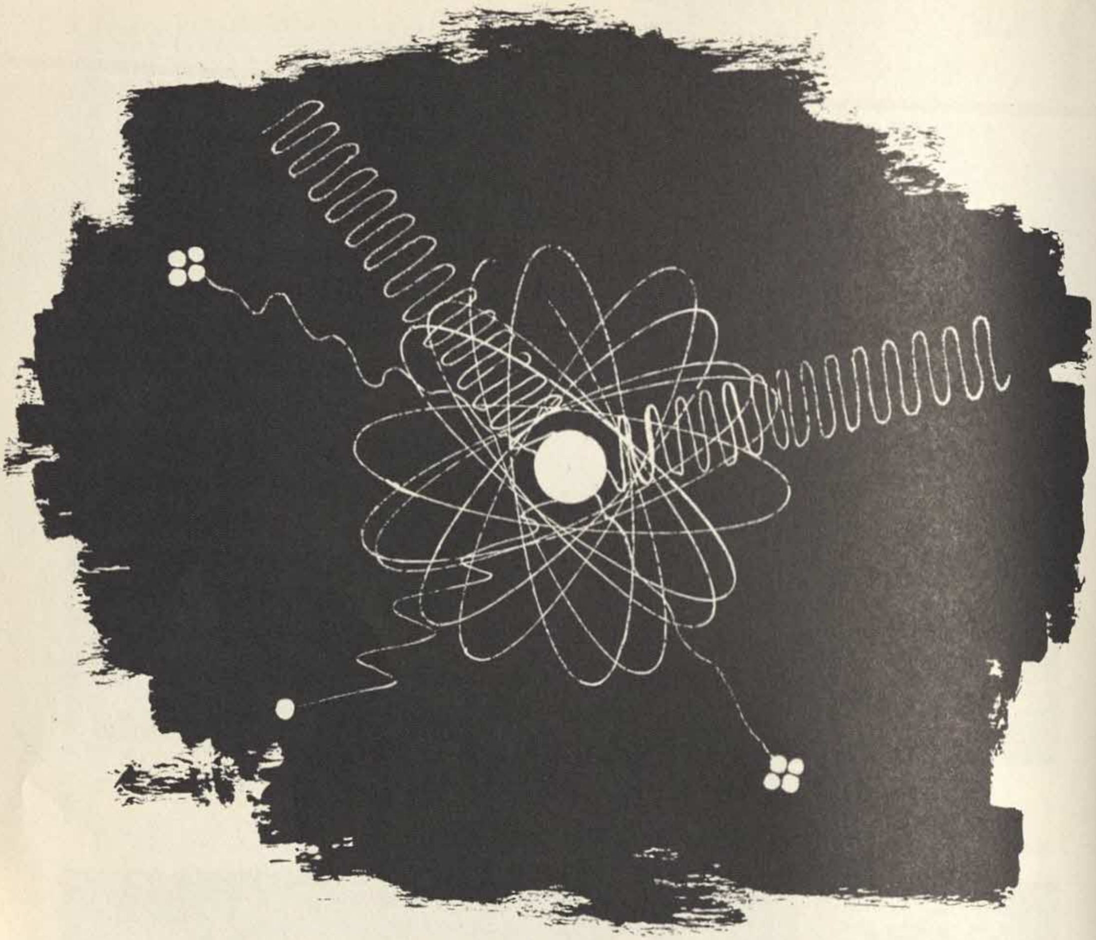
In an atomic bomb many, many U-235 atoms are split. The splitting of only one atom would be no explosion—it would be hard to notice except with the help of a sensitive instrument. In an atomic bomb, splitting of one nucleus is caused when that nucleus is hit by a neutron, which it absorbs. Immediately after the absorption of the neutron, the nucleus splits. Following the splitting, each of the new lighter nuclei give off one or two neutrons. These several neutrons hit other U-235 nuclei, causing them to split. Each of those splittings gives off several neutrons, and so on. This is called a *chain reaction*. Can you see how this chain reaction progresses? Let us suppose that each splitting process gives three neutrons. The first neutron makes a splitting of the nucleus that gives three neutrons. These three neutrons make three splittings that give 9 neutrons. 9 make 27, and so on. The number of nuclear splittings becomes, in succession: 1, 3, 27, 81, 243, 729, 2187, 6561, 19683, etc. Each step is called a generation, and each generation takes only about a millionth of a second. In a very short time the energy released as heat becomes very very



The atomic power plant at Indian Point, New York



This steam-electric generator inside the power station is driven by the energy from the atom



great, and the material so overheated that it blows apart in a tremendous explosion.

Certain atoms break apart by themselves. They do not need to be hit by the atomic particles that man shoots at them. Atoms that break apart are called *radioactive* atoms. Do you remember which radioactive atoms the Curies worked with?

The radioactive elements are numbered 84 through 92. Because of their size, they seem to be unstable and break apart into other smaller atoms. For example, a large uranium atom breaks down into radium by losing some of its particles. Radium breaks down into the element polonium by losing particles also. Finally polonium breaks down into lead, which is a stable atom that will not break down any more.

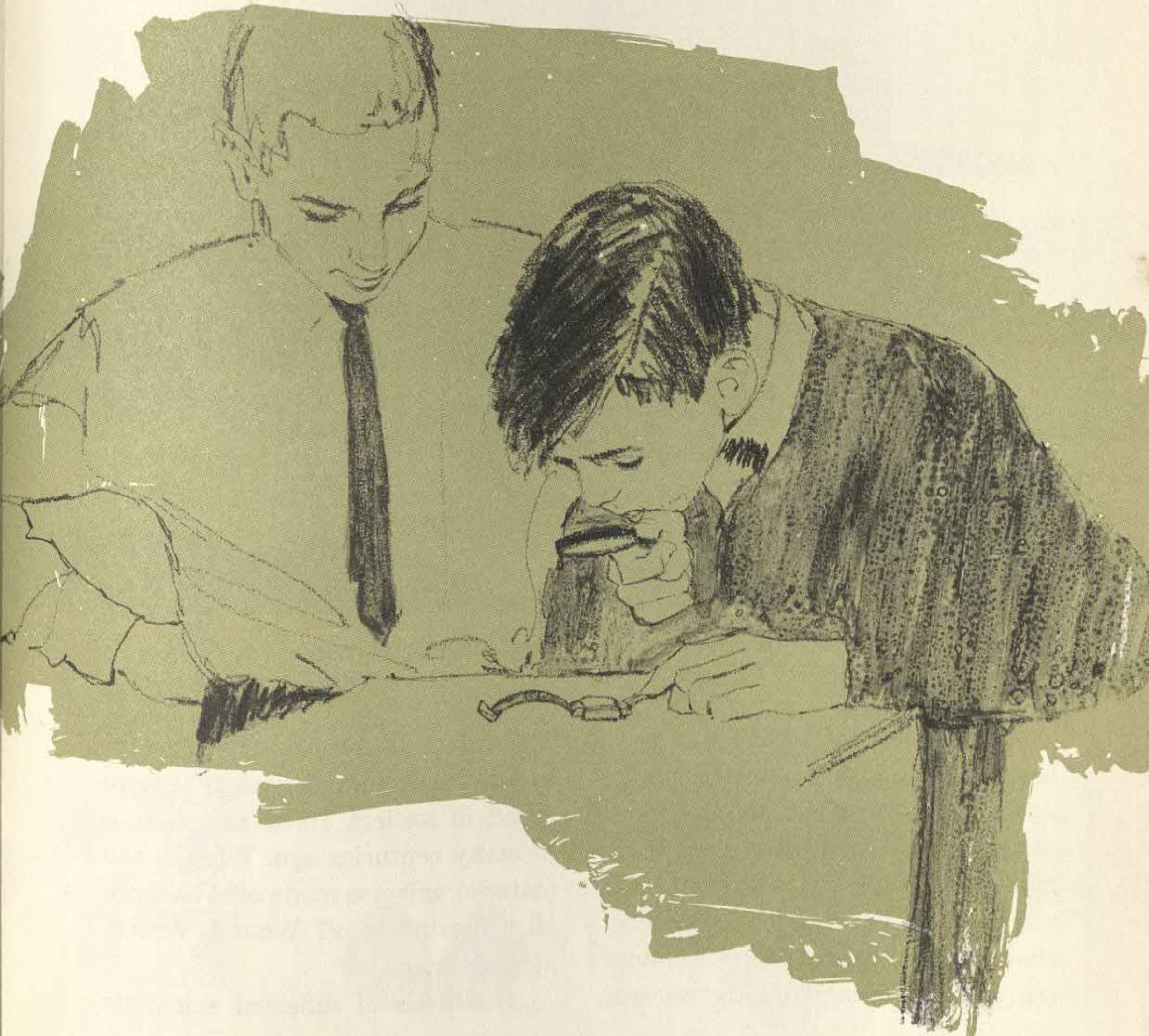
In a watch that glows in the dark there is a coating of material that glows when atoms break apart and strike it. A radioactive substance, such as radium, is placed near the coated material in a watch of this type. The coating gives off light when hit with these fast moving particles.

ACTIVITY

Let your eyes become used to a darkened room. Use a strong magnifying glass and look closely and carefully at a radioactive watch dial. What do you see? What do you think causes each flash?

Place the watch under a low-power microscope. Do you get a better view? Each flash represents a collision between an atomic particle and the coating material.

Other unstable atoms have been made in special laboratories. These atoms may break apart because they are larger than the uranium atom. They are so unstable that they break into smaller parts within seconds or fractions of a second after they are made.



The George Washington—First Atomic Submarine

The models with which you have been working in this unit have grown and changed over the last two thousand years. In the future, as we learn more and more about the physical world, the model will, no doubt, change again. We may have to revise our present ideas about the nucleus of the atom. We may find it necessary to ask the same questions that were asked in ancient India and Greece so many centuries ago. What is the material universe made of? What are all things made of? What is matter actually made of?

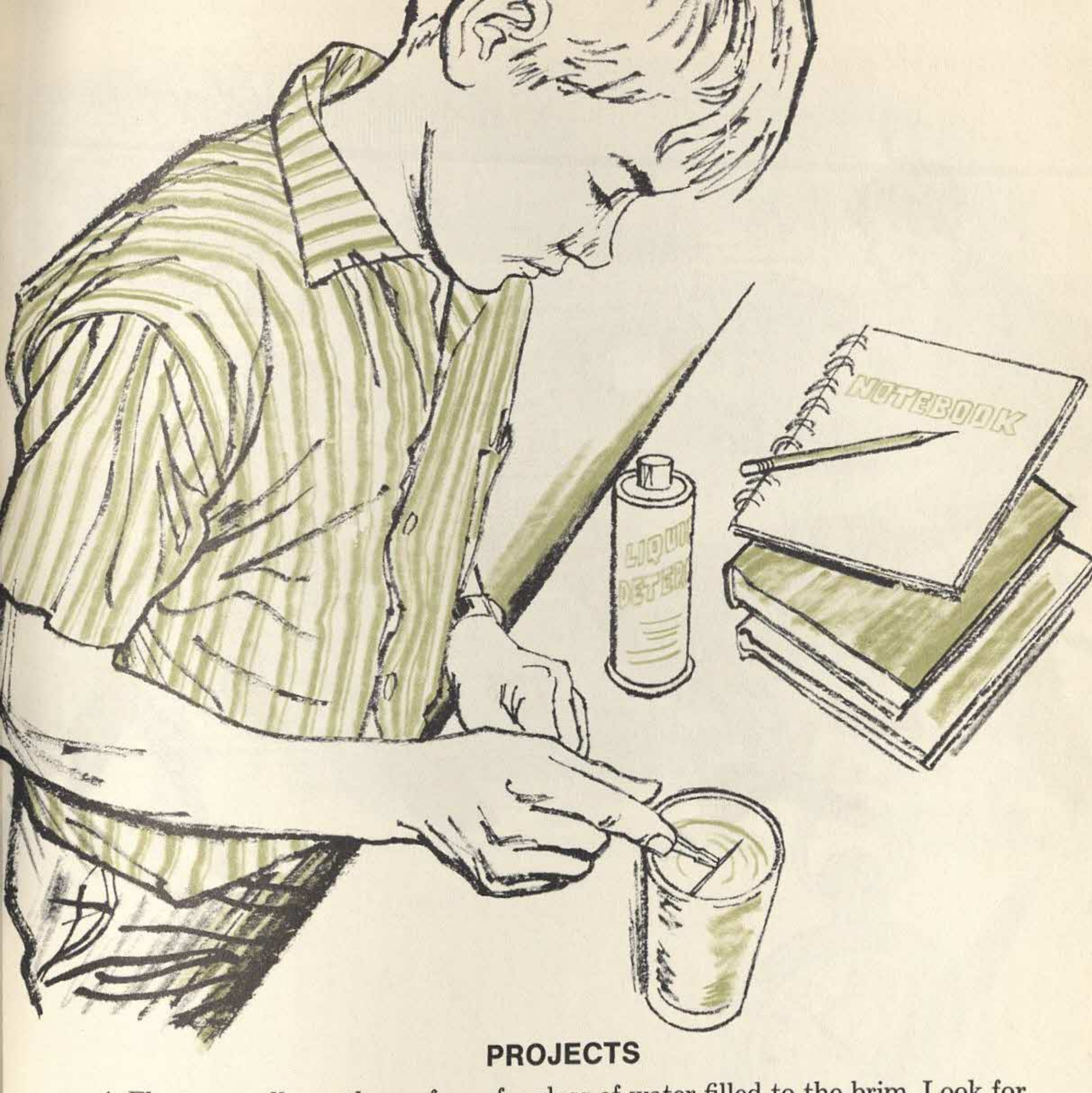
Hundreds of different scientists

from all over the world, using good sense and reason, have built upon the work of scientists before them to create the atomic model that we know and use today. Efforts are being made at the present time to harness the energy of the atom for peaceful purposes.

Scientists expect that the atomic model that we have been studying will remain essentially unchanged for many years. Someday, however, scientists hope to understand why electrons, protons, and neutrons are the building blocks of matter and why protons and neutrons are so much heavier than electrons. As we learn more about the atom and what holds the atom together, we shall be in a much better position to explain many things about the universe which are still a mystery.

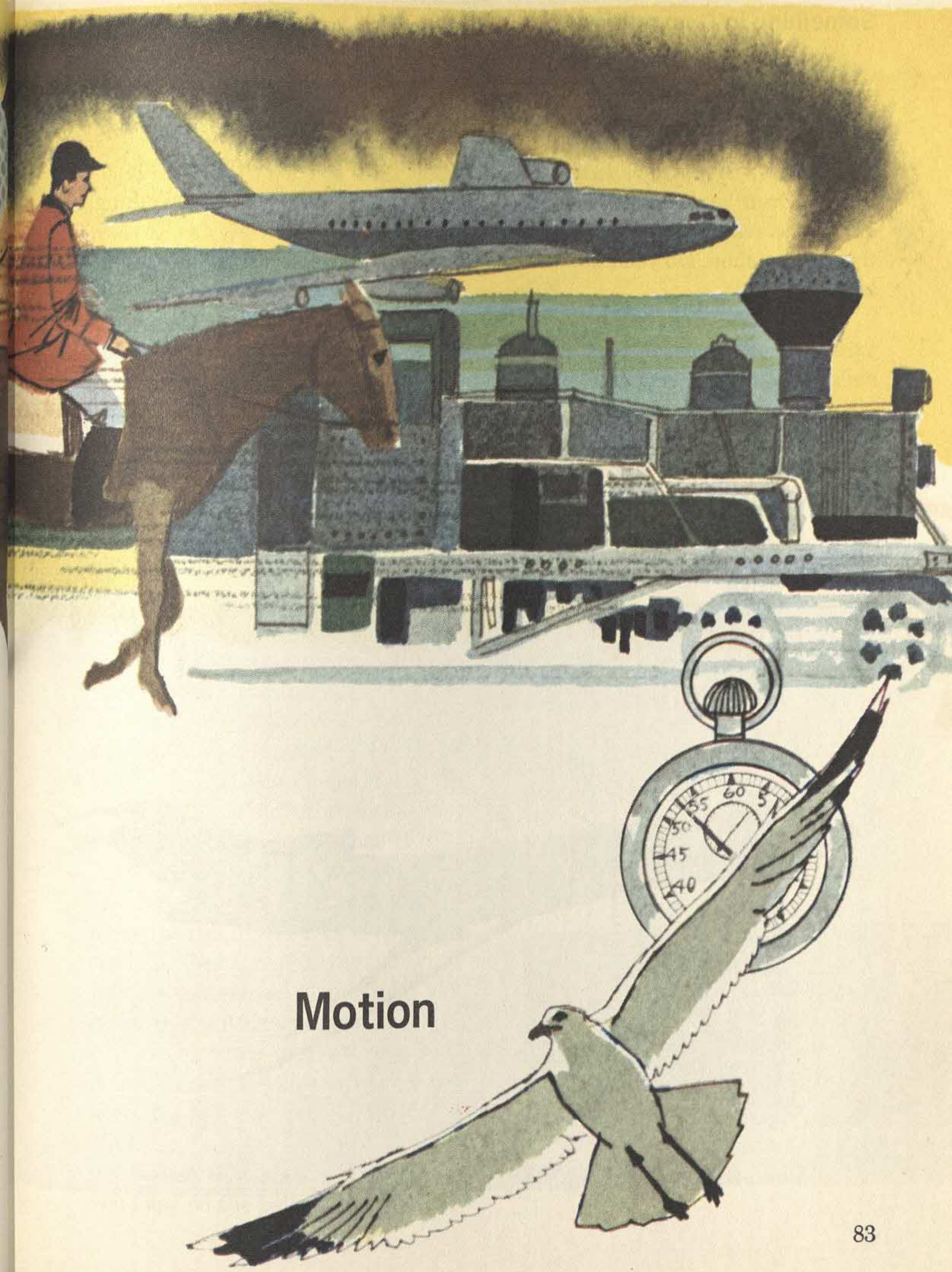
THINK

1. Do atoms and molecules really exist? How do you know?
2. What would you have to do to prove that all things are made of atoms and molecules?
3. When is a model considered a "good" model?
4. What are some limitations in the use of models to explain scientific "facts" about atoms?
5. What is the best evidence available to support the theory that matter is made of moving molecules?



PROJECTS

1. Float a needle on the surface of a glass of water filled to the brim. Look for the "skin" on the water. Try to find out why this skin exists. Add a drop of detergent gently to the water. After you observe everything you can about this, try to find out from science books and magazines why these things happen. What is meant by surface tension?
2. Look for different liquids in your kitchen. Which of them seem to flow very easily? Which of the liquids flow more slowly? Try to find out why. Try to discover the effect temperature has on the flow of liquids. Think of a way to measure the flow. Make many measurements. Keep a data table. Write a report about this and if your teacher selects you, present your report to the class.



Motion

Something in Common

An airplane flies from New York to San Francisco; a train travels from Chicago to New Orleans; a cowboy rides the range; a batter hits a home run and a chicken runs across the road. All these have one thing in common. Do you know what it is?

The front wheel of a bicycle turns; a coin spins; a year passes; children ride a merry-go-round; a boy spins a top. All these, too, have something in common. What is it?

The pendulum on a grandfather clock swings; a dog wags its tail; you swing your arm, blink your eyes, walk across the school yard. All these, too, have one thing in common. What is it? Would you agree that *motion* is common to all of the examples provided?

Observing Movement

It is easy to say that something moves, but it is not always as easy to tell exactly *how* something moves. In the following activities you will have a chance to observe carefully how something moves. You may wish to repeat each activity several times to be sure of what you observe.

OBSERVE

Take a sheet of paper from your notebook. Crumple it into a ball. Put the paper ball on the top of your

desk or table. Hit the ball gently with your finger. What made the ball move? Did it move in a straight line? Why didn't the ball move before you hit it? Do you know why the ball stopped moving? Do you know why the ball moved in the direction that it did? How could you make the ball go faster than it did?

Put the paper ball on your desk again. This time, blow on it. What made the ball move? Did it move in a straight line? Can you measure how fast the ball moved? How could you make the ball move faster?

Do you have to blow very hard before the ball begins to move? What keeps the ball from moving when you blow very gently? Can you blow on the ball so that it rolls evenly? Can you blow on the ball so that it skids?

EXPLORE

Throw the ball up in the air. Does the ball go very high? How could you make it go higher? Throw the ball up in the air again. Watch the ball very closely. When does the ball move fastest? When does the ball move most slowly? Do you think it ever stops in the air?

Work with a classmate, using a small rubber ball to play catch. Watch the way the ball moves when you throw it. Does the ball go straight from you to your classmate? What do you feel when you catch the ball?

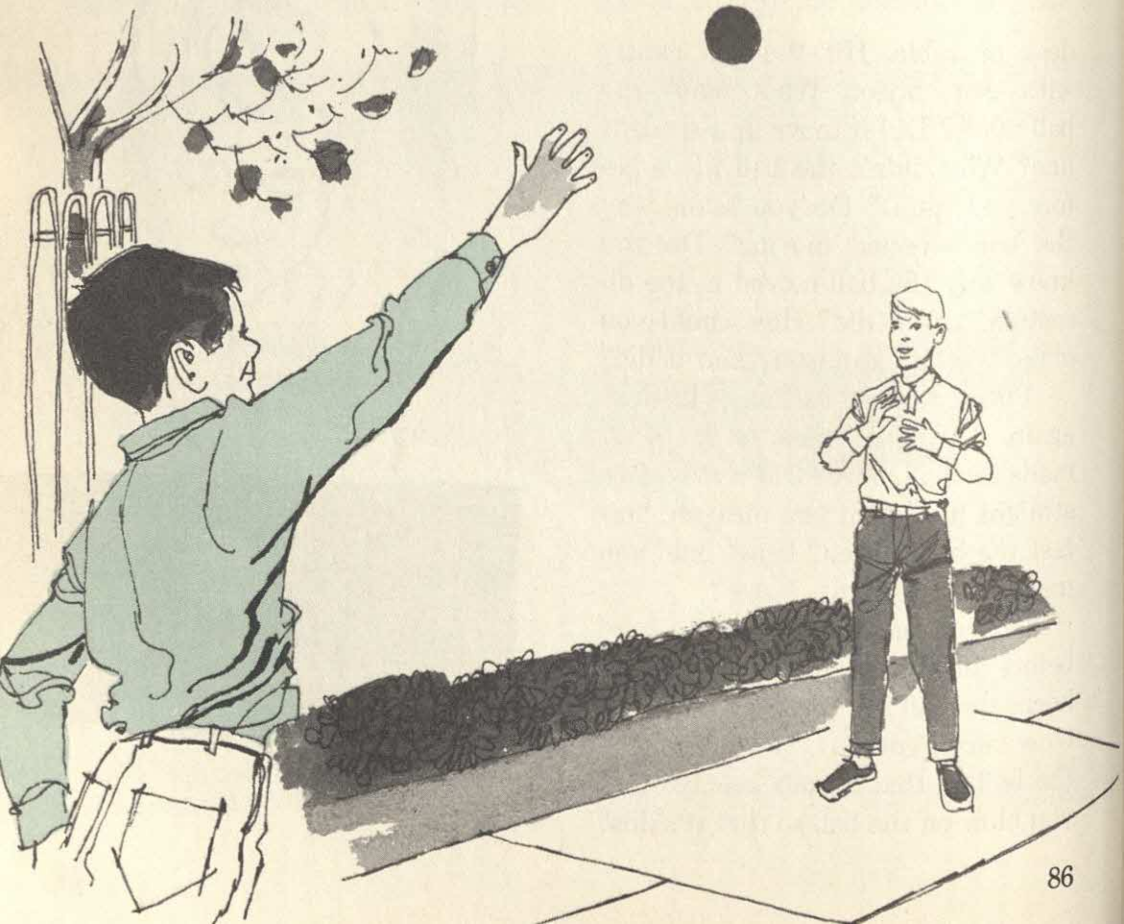
Can a paper ball be thrown so that it goes down and then comes back up?

Force

When you threw the ball to your classmate, he stopped the ball when he caught it. If your neighbor had not caught the ball, what would have stopped it?

If the school building were not there, what would have stopped the ball? If the ground were not there, what would have stopped the ball?

When we talk about motion and things that move, we often use words



like push, pull, tug, jerk, and shove to describe what makes objects move. Science has one word that means all of these things. That word is *force*.

DESCRIBE

Put your hands together as shown in the picture. Push. What do you feel? Hook your two forefingers together. Pull. What do you feel now? Stand up and jump. Can you feel a force pulling you down? Slap your desk. Do you feel this force?

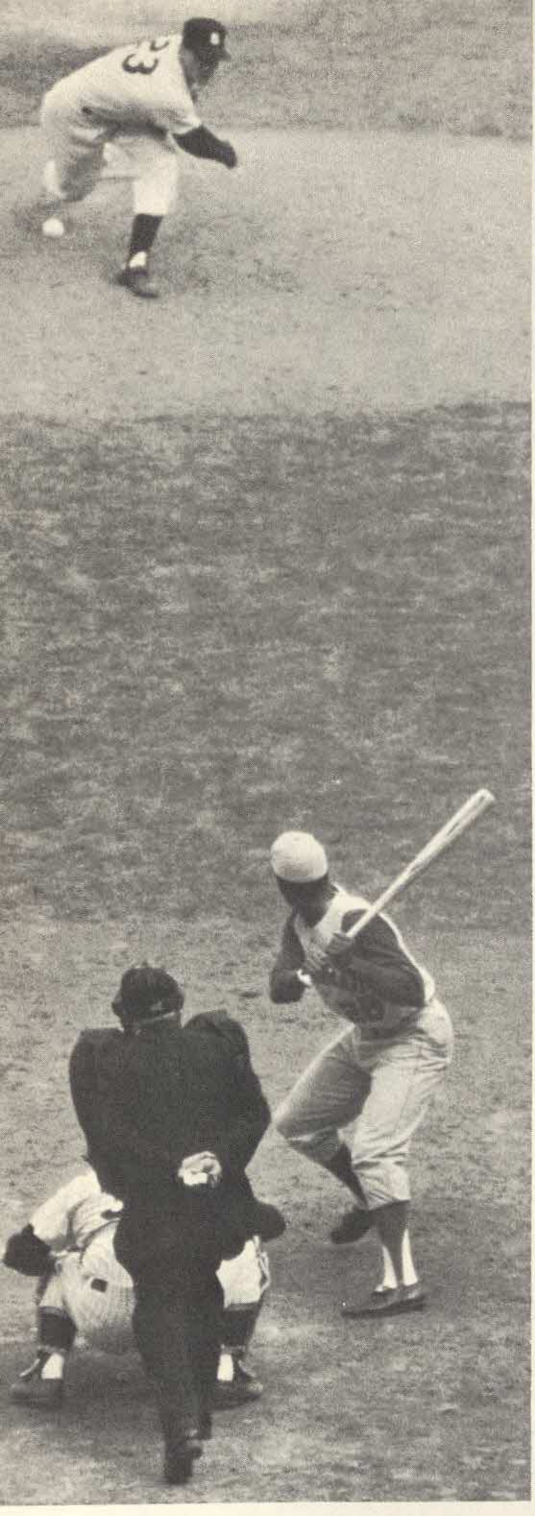
A force always has a direction. When you placed your hands together and pushed, what was the direction of the force put out by your right hand? What was the direction of the force put out by your left hand? When you hooked your forefingers together and pulled, what was the direction of force put out by each hand? When you stood up and jumped, in what direction was each force?

Two other words are often used with the word force. These words are *exert* and *apply*. When you are standing near a wall, you can exert a force against the wall by pushing it. You can apply a force on this book. Let us agree to use the words exert and apply to mean the same thing.

Ideas About Motion

Here is a statement to think about. *Nothing will move unless some force is applied*. Do you think this statement is true? How do you know?

Here is another statement. *If an object is moving, it will continue to*



When might this ball change direction?

move unless some force stops it. Do you think this statement is true? When you threw the paper ball to your neighbor, what started the ball moving? What stopped the ball?

When you blew on the paper ball, what started the ball moving? What stopped the ball?

When you threw the ball up in the air, what stopped the ball? What started the ball? What caused the ball to change direction? Would you agree that it takes a force to start or stop the ball?

When you and your classmate threw the ball to one another, you may have observed that the ball always followed a curved path. The amount of curve depended on how hard the ball was thrown, but some curve was always there. Do you know why? Do you know what force causes the path of the ball to be curved?

Here is another statement to think about. *An object in motion will continue to move in a straight line unless some force causes it to change its direction.* How would you check the truth of this statement?

A pitcher throws the ball to the batter; the batter hits the ball high into the air and a fielder catches it. Can you count how many times the ball changes direction? What caused the ball to change direction each time? If the batter had not hit the ball, would the ball have changed direction? Why? When does the ball travel the greatest distance?

Measuring Force and Friction

Have you ever walked on ice or on a newly waxed floor? Do you know why they are so slippery? Have you ever walked through the sand at a beach or on a piece of rough concrete? Do you know why they are *not* slippery? Whether or not something is slippery seems to depend on a force that exists between two touching surfaces. This is the force called *friction.*

Friction is a force. The word friction comes from a Latin word that means "to rub." In the following activities you will measure differences in this force as various surfaces are rubbed against one another.

OBSERVE

Place a book on the edge of your desk. Blow on a small paper ball so that when it moves, it will hit the book at an angle, as in the picture. What happens? What causes the ball to change direction?

When an object is moving, there are two important ways it can be stopped. The object can either run into something such as your hand or a wall, or the object can be slowed down and then stopped by a force called *friction.* What stopped the paper ball when you blew it across your desk? What stopped the paper ball when you threw it up into the air? What stopped the paper ball when you threw it to your classmate?

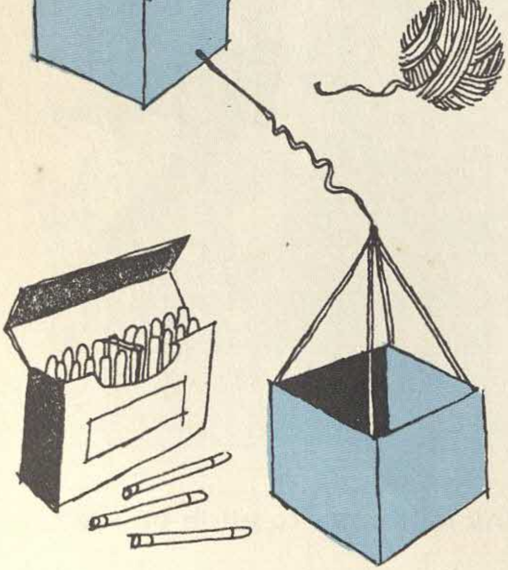
Why is it easy to glide on ice?

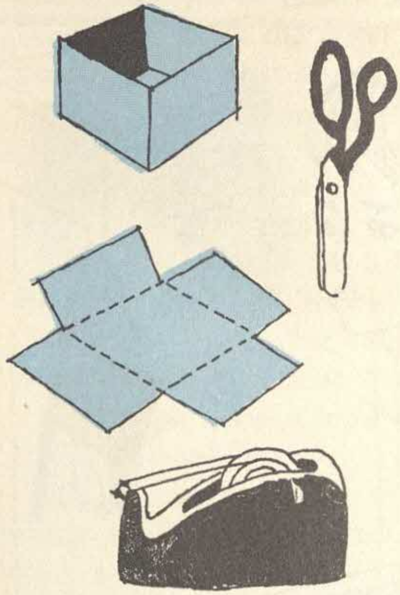
EXPLORE

Make a box like the one in the drawing out of a piece of notebook paper. Hold the corners together with paper clips, glue, or tape. You do not have to make the box. It is important only that you have a very lightweight box into which you can put things.

Place your paper box on the top of a flat desk or table. Blow on the box. Do you have to blow very hard in order to make the box move? Make the box move by pushing it. Did you have to exert very much force to make the box move?

Do you have to apply very much force to the box to keep it moving? What happens when you stop applying force to the box? How far does the box move after you stop applying force? What stops the box?





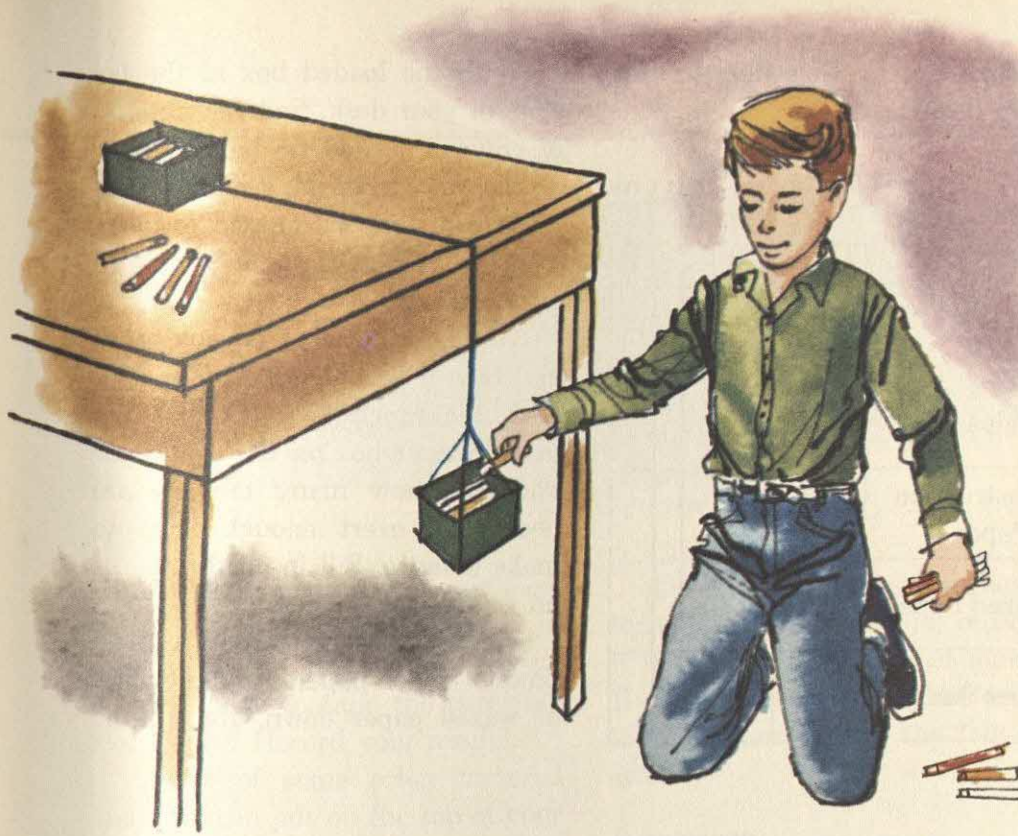
MEASURE

Find ten unused crayons or pieces of chalk that are about the same size. If you cannot find either crayons or chalk, use marbles.

Put all ten crayons in the paper box. Blow on the box. Does it move? Is it easier or harder to move than when it was empty? Push the box with your finger. Do you have to apply more force now, before the box begins to move?

Take five of the ten crayons out of the box. Now blow on it. Does it move? Is it easier or harder to move than before? Push the box with your finger. Do you have to apply more or less force to move the box now?

Try to think of some way to measure the amount of force needed



to move the box. Can you use some weights or a spring balance? Measuring "how much" is very important in science. Can you tell why this is important?

RECORD

Work with a partner. Make sure that you have two paper boxes and twenty crayons. You can use more crayons if you wish.

Use a piece of string 24 to 36 inches long to connect the two paper boxes. Using tape, staples, or glue, fasten the string to the boxes as shown in the picture. Attach the string to the top of one box and to the bottom of the other, as shown in the picture. Place the box that has the string attached to the bottom on your desk. Put three crayons in this box. Let the other box hang over the edge of the desk. What happens when you put one crayon in the box that is hanging over the edge? What happens when you put two crayons in the box hanging over the edge?

Now put ten unused crayons in the box on the table. How many crayons must you put in the hanging box before the box on the table starts to move? Do this experiment several times. Does it always require the same number of crayons to move the loaded box? Be careful that you do not give an extra push when you are putting the crayons in the box.

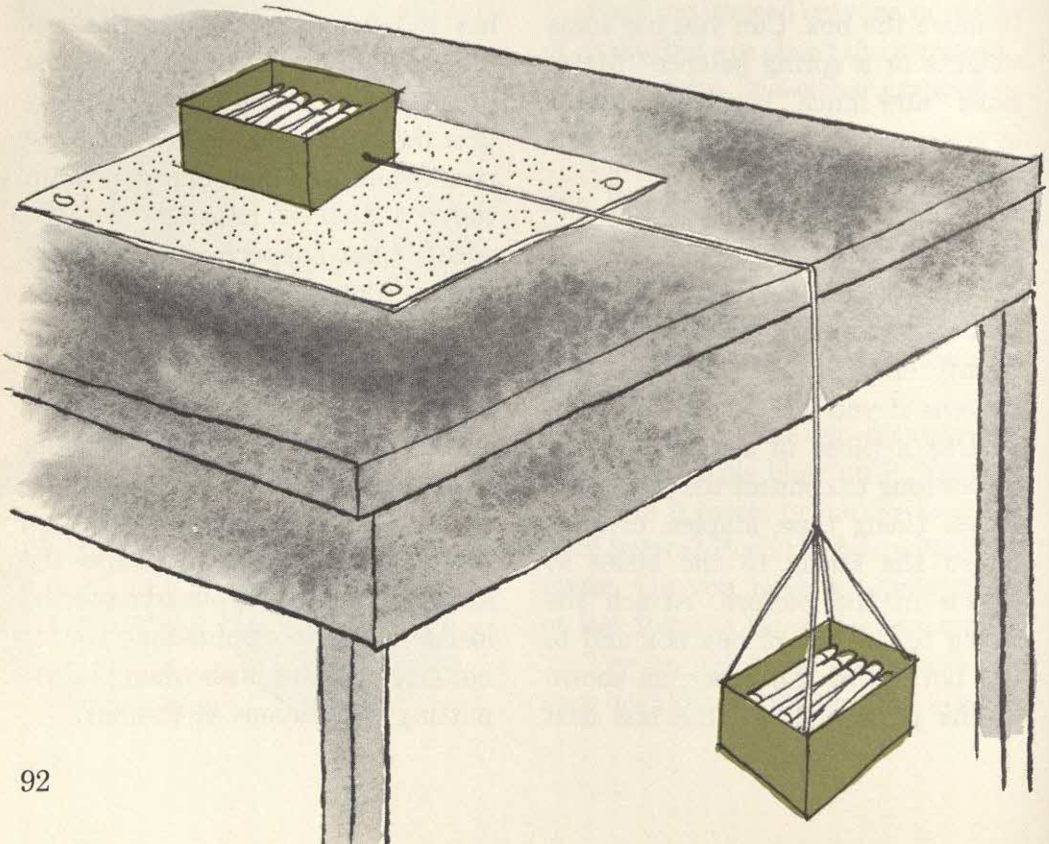
Make a data table like the one shown below:

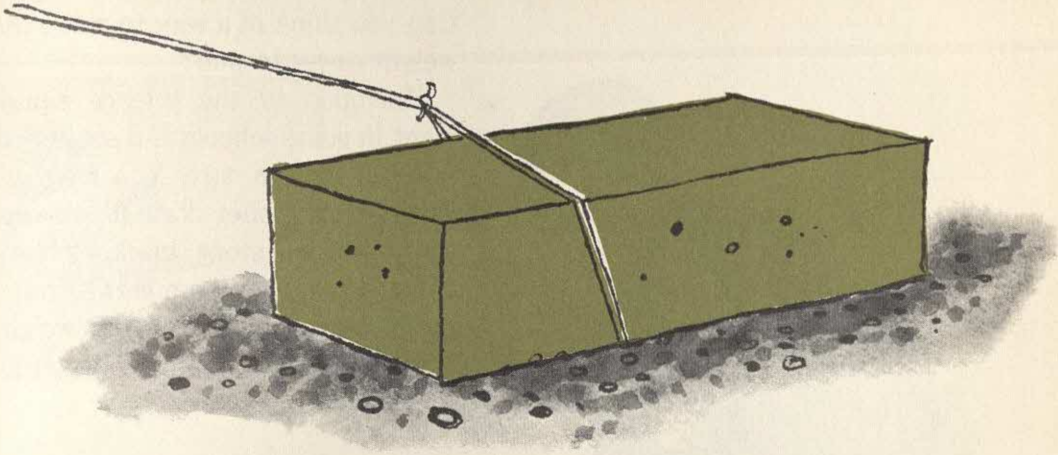
Surface	Number of crayons in a load							
	3	4	5	6	7	8	9	10
Table Top								
Sandpaper								
Construction Paper								
Waxed Paper								
Other Surface								

With the loaded box at the far edge of your desk, find the number of crayons needed to make it slide all the way across the desk. Find the number of crayons needed to move loads of 3, 4, 5, 6, 7, 8, 9, and 10 crayons.

Get a large sheet of sandpaper and tape it to the top of your desk with the rough side up. Put the loaded paper box on the sandpaper and find how many crayons are needed to exert enough force to make it move. Fill in all the spaces on your table.

Repeat the same activity using a piece of waxed paper. Tape the piece of waxed paper down. Record the





results on your table. Now put some construction paper on the top of your desk and repeat the activity. Do you have to tape the construction paper? Record your results.

Think of some other material that you can put on the top of your desk. Repeat the activity one more time and fill in the last row of spaces on your table.

Look at your table. Can you explain the results? What do you think would happen if you sat on a piece of waxed paper and went down a playground slide? What do you think would happen if you sat on a piece of sandpaper and went down a slide? Would you agree that surfaces differ in the amount of friction developed?

Can you use the data collected in your experiment to make predictions? Would the results have been the same, if the paper box had been larger or smaller? How could you find out?

Does it take the same amount of force to start to move an object as it does to keep the object moving? If you are not sure of the answer to that question, try the following activity.

OBSERVE

Set up two paper boxes as you did before. Find the number of crayons required to make a box with ten crayons in it move across a level surface. Now remove one crayon from the box that is hanging down. Will the loaded box move? Give the loaded box a push. Does it start to move? Does it continue to move? How many crayons can you remove and still have the box continue to move when you give it a push?

COMPARE

Find a large stone, a brick, or a large block of wood. Tie a string or cord around the heavy object and pull it across the floor or playground.

Is it very hard to pull the weight? Can you think of a way to make the weight easier to pull?

Included in the science equipment in some schools is a small cart called a friction cart. You may use this cart or a roller skate for this activity. Put the stone, brick, or block of wood on the friction cart or roller skate. Now try to pull the weight across the floor. Is it easier or harder to pull? Why?

OBSERVE

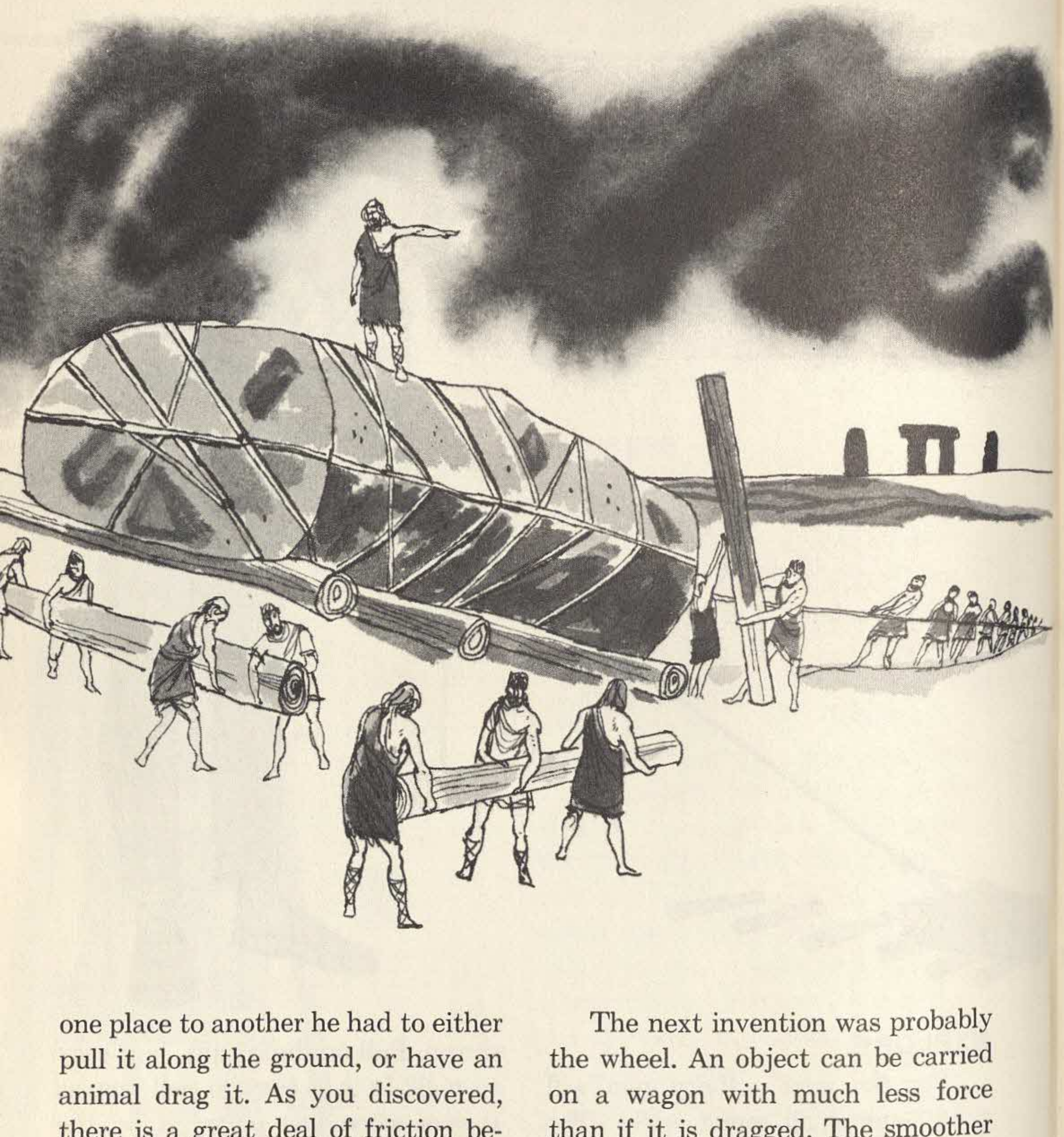
Stand on a solid chair or ladder and drop a piece of paper. Does it fall very fast? What determines how fast it falls? Take the same piece of paper and crumple it into a ball. Drop the paper ball. Why does the paper fall faster now? What determines how fast the paper ball falls?

If you put your hand out of the window of a moving automobile, what would you feel? If you put your hand out of the window of an automobile that is standing still, what would you feel? What causes the difference? Why? If there were no friction between a moving object and the surface over which it moves, would that object continue to move? What would stop it? If an object moves through the air, will the force of friction between the object and the air eventually stop the object? Make a list of all the things you can think of which will stop an object that is moving.

EXPLORE

For the next activity you will need some small round sticks. The exact size is not important. Sticks with diameters ranging from ⅛ of an inch to 1 inch, and lengths of from 4 to 6 inches may be used. Arrange a row of sticks on the floor as shown in the picture. Place the brick or weight on several of the sticks as shown. Pull on the weight. Is it easy to pull? Is it as easy to pull now as it was when you pulled it on the friction cart? Why? □□

During the entire history of man, from the time he lived in caves to the present, there has been a constant struggle to reduce the effects of friction. In very early times, when a man wanted to move something from

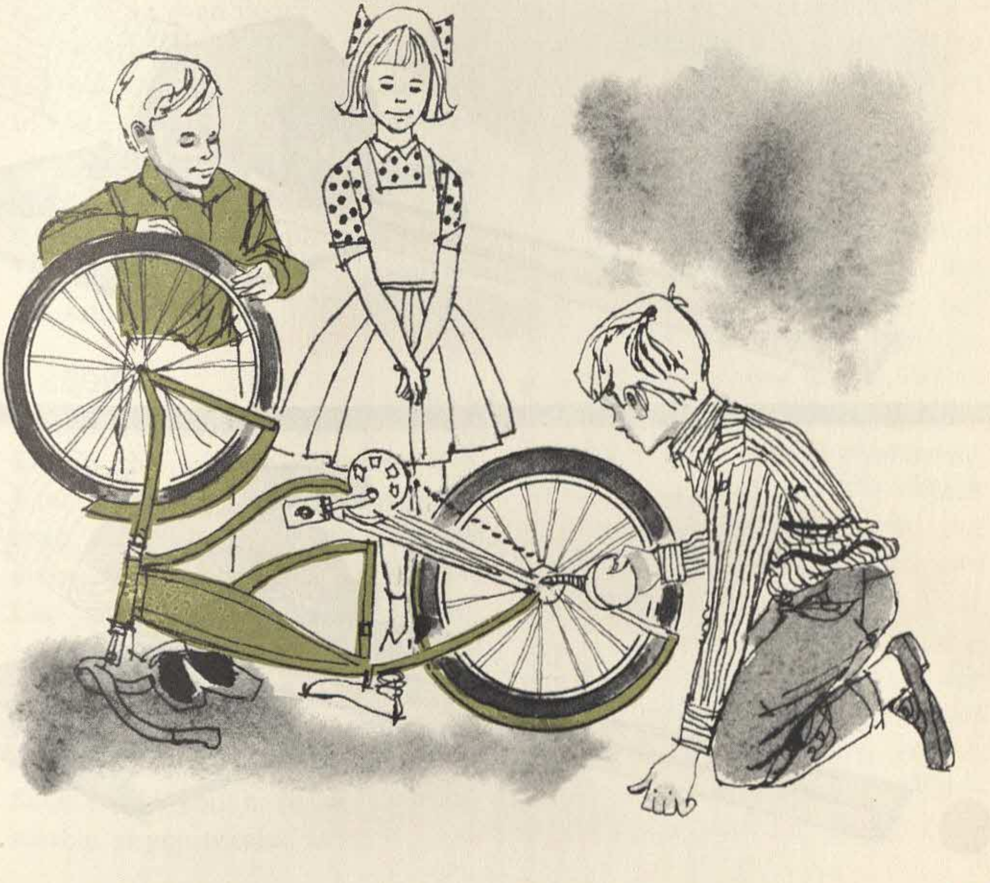


one place to another he had to either pull it along the ground, or have an animal drag it. As you discovered, there is a great deal of friction between a flat object and a flat surface when the one is moved along the other. The use of rollers was probably the first way man had of improving the situation. A heavy object can be moved with a very small force when it is on rollers.

The next invention was probably the wheel. An object can be carried on a wagon with much less force than if it is dragged. The smoother the road and the rounder the wheel, the easier it is to pull a wagon. For this reason, the next development was probably the smoothed and paved road. The very best road that has ever been built is the railroad track, where smooth steel wheels

roll on a smooth steel track. A railroad car with a load of 20 tons can be moved by a force of less than 100 pounds. A truck on rubber tires needs a force of nearly 10 times as much before it will move. The reason that trucks are used at all, is that their motors provide a great deal of force cheaply, and trucks have a greater freedom of movement than trains.

The major point of friction in wheels is at the place where wheels turn on their axles—this part of the machine is called the *bearing*. The first bearings were most likely wooden, with animal fat serving as a lubricant. When smooth metal bearings were invented there was much less wear, and wheels turned much more smoothly. Today we have many kinds of bearings. Roller bearings and ball bearings are very common. A bicycle has at least thirteen sets of ball bearings. A watch has bearings made of rubies, and modern automobiles have bearings that will help the wheels turn for tens of thousands of miles with little or no attention.

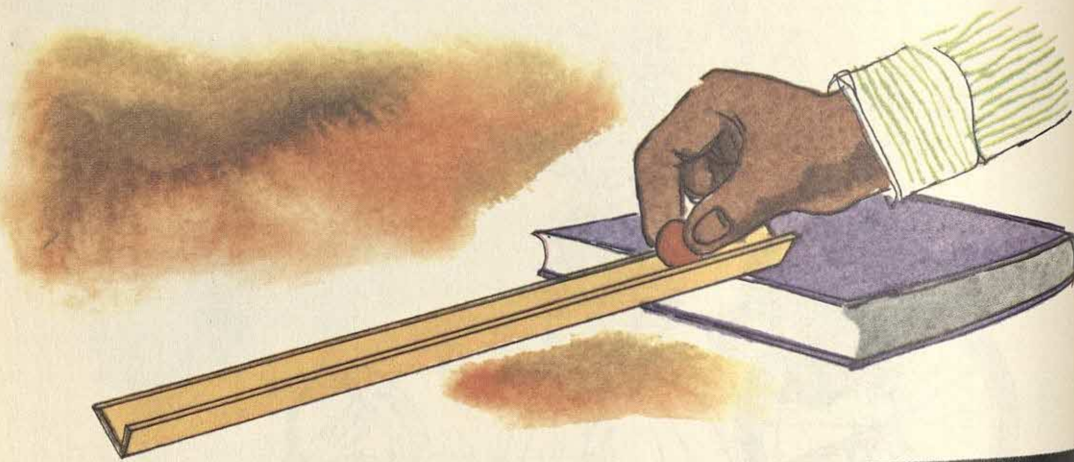


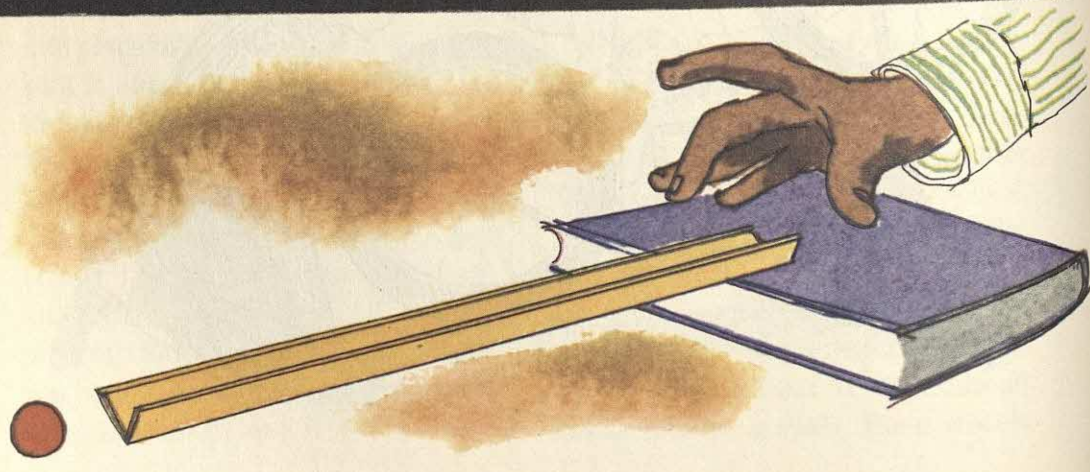
Measuring Moving Weights, and Distances

For this activity, you need to make a track for a marble. You may use either a wooden trough, as shown in the picture, or a piece of stiff paper folded to form a V-shaped groove. Make sure that the track is 1 inch above the floor at the upper end. Use a book of that thickness to support the track. If your classroom floor is not smooth, cover the section you use with a large sheet of paper.

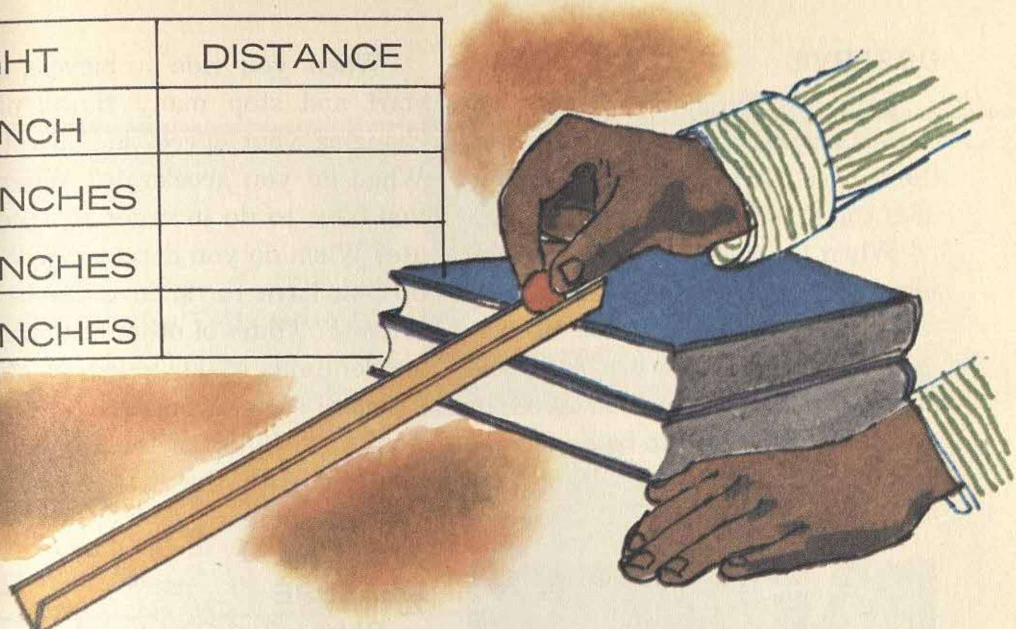
Place the marble at the top of the track and let it go. How would you measure how far the marble goes? How far did the marble go? Do the activity several times. Does the marble always go about the same distance?

Use a piece of paper to mark the distance the marble rolled. Lower the groove so the marble is only ½ inch above the floor when you let it go. How far does the marble go now? Do this activity several times. Vary the height of the marble track. Mark how far the marble travels with pieces of paper. What do you notice about the distance the marble





HEIGHT	DISTANCE
1 INCH	
1½ INCHES	
2 INCHES	
2½ INCHES	



travels? Why must this activity be done on an even floor?

Now raise the end of the groove so that the marble starts about 2 inches above the floor. How far does the marble go now? Do this activity several times. Again, mark how far the marble goes with pieces of paper. Does this marble always go about the same distance?

PREDICT

Make a chart like the one above. Fill in the average distances you found when you let the marble go from ½ inch, 1 inch, and 2 inches above the floor. Study your chart. Can you predict how far the marble will go, if it is released ¼ inch above the floor? How far do you think it will travel if it is released 3 inches above the floor? How far above the floor would you have to start the marble, if you wanted to make it go 30 feet? How would you check your predictions? What finally stops the marble? How can you make the marble go farther without starting it higher?

EXPLORE

Find a steel ball bearing and a marble that are about the same size. Which is heavier? Roll both the ball bearing and the marble down the groove from the same height. Which goes farther? Which goes faster? How can you be sure? Do this experiment several times. Are the results always about the same? If someone else does the experiment, will he get the same results? If you had a glass marble, a steel ball bearing, and a wooden marble, all the same size but of different weights, and you let them roll from the same height, which would go farthest? Which would go the shortest distance?

OBSERVE

Let a marble roll down the groove from a height of 1 inch. When does the marble move most slowly? When does the marble move most rapidly?

When the speed of a moving object is increasing, scientists say that it is *accelerating* (ak-SELL-ur-*ayt*-ing). When does the marble accelerate? When an object's speed is decreasing, it is said to be *decelerating* (dee-SELL-ur-*ayt*-ing). When does the marble decelerate? □□

When does the bicycle accelerate?

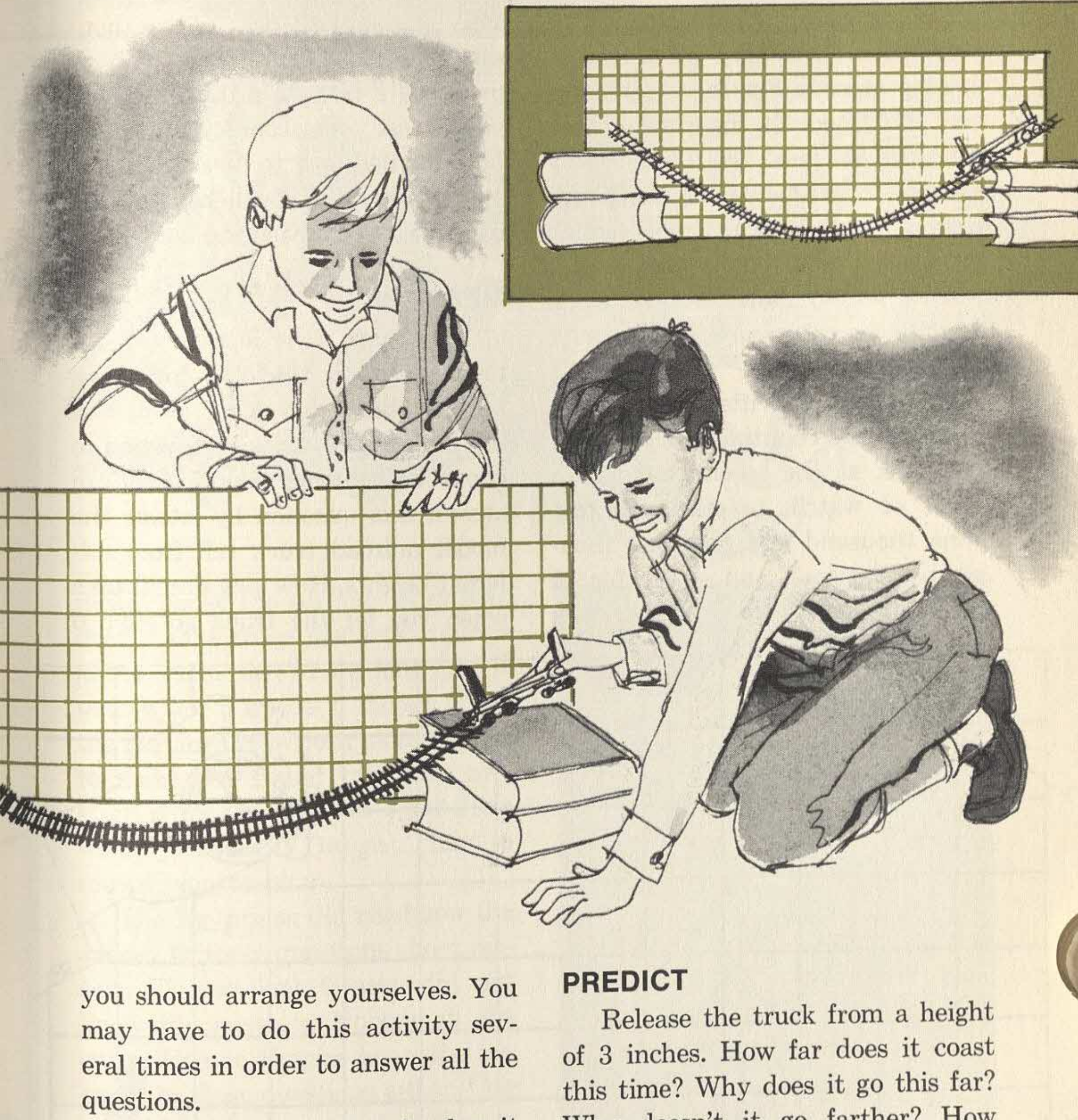
When you ride a bicycle, you start and stop many times, often changing your speed and direction. When do you accelerate? What do you have to do in order to accelerate? When do you decelerate? What do you have to do in order to decelerate? Think of other examples of acceleration. Make a list of them. Think of some examples of deceleration. Make a list of them. Compare your list with the lists of some of your classmates.

MEASURE

Obtain a 3-foot length of HO gauge model railroad track, and two sets of model railroad wheels. A set of railroad wheels like the one shown in the picture is called a *truck*. You will also need a ruler or yardstick and a large piece of cardboard.

Bend the railroad track into the shape shown in the picture. Use some books or some blocks of wood to support the two ends of the track. Now draw 1-inch squares on the large piece of cardboard. Stand the cardboard up behind the railroad track.

With everything arranged as it is in the picture, place the truck on the tracks exactly 6 inches above your work surface. Use the cardboard with the inch-squares to find a height of exactly 6 inches. Now, while you let the truck go, have a classmate look very carefully at the other end of the track to see how far the truck coasts. The picture shows about how



you should arrange yourselves. You may have to do this activity several times in order to answer all the questions.

Let the truck go. How far does it travel? Does it run off the end of the track? Why? What stops the truck? How many times does the truck coast back and forth before it stops? Where does the truck stop? Why does the truck stop there?

PREDICT

Release the truck from a height of 3 inches. How far does it coast this time? Why does it go this far? Why doesn't it go farther? How many times does the truck coast back and forth before it stops? How many times do you think the truck would coast back and forth, if you released it from a height of 5 inches? Try it and see. □□

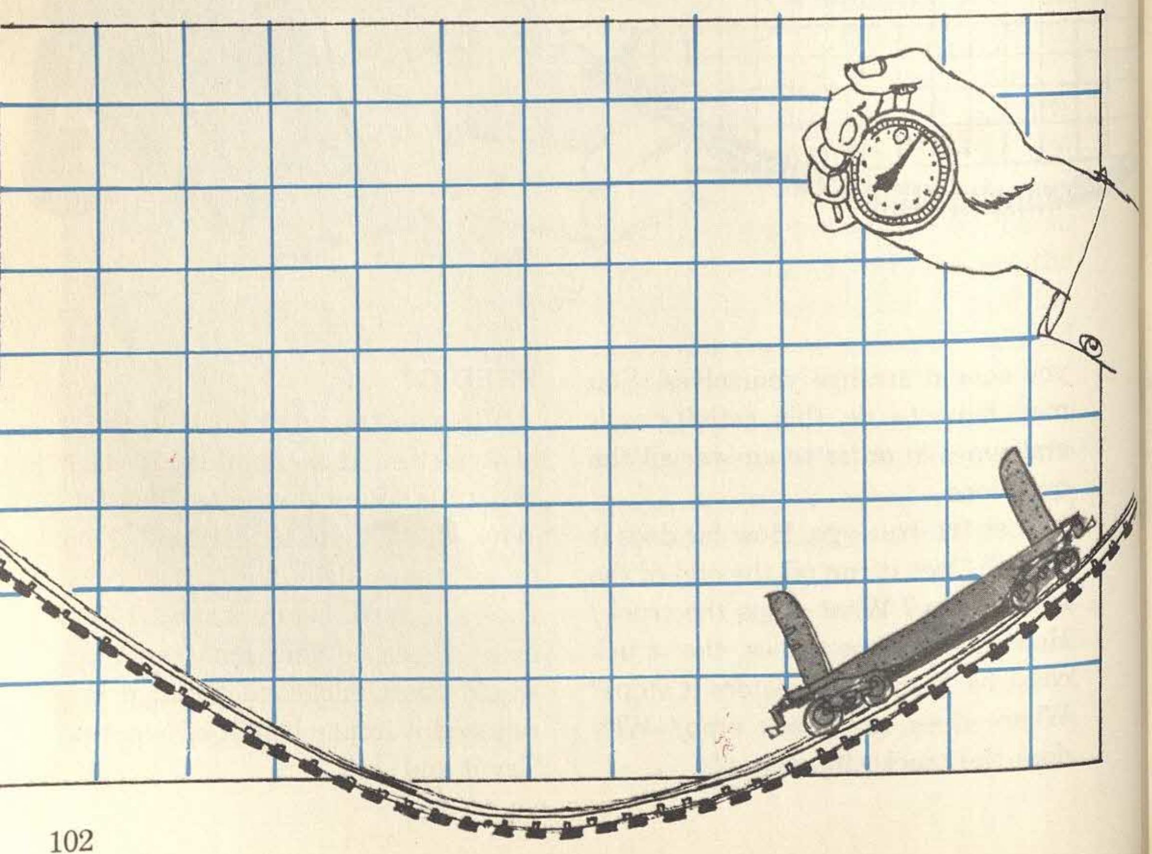
Timing a Moving Object

As you continue to study motion, you will need to time a number of moving objects. For these activities you will need an instrument that measures seconds. One of the most accurate instruments for measuring time is a stop watch. If you cannot get a stop watch or a wrist watch with a second hand, use the clock in your classroom, provided it has a second hand.

For some activities, you can do very well by counting aloud. While you look at the second hand of a clock or watch, practice counting "one thousand and one; one thousand and two–" and so on, for 10 seconds. With a little practice you should have no trouble taking exactly one second to say "one thousand and one." After you have practiced a bit, ask a friend to help you to test your accuracy. Once you have learned how to measure a second this way, you will have a very handy way of measuring time.

MEASURE

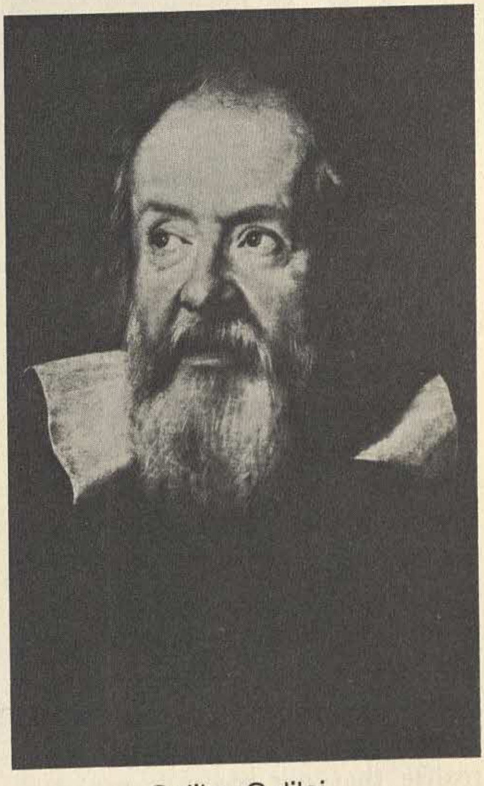
How long does it take for the model railroad truck to roll down hill, up the other side, stop, and roll back in the opposite direction to *about* its starting point? You can answer this question by letting the model railroad truck roll from different heights. How long does it take when you let the truck go from 6



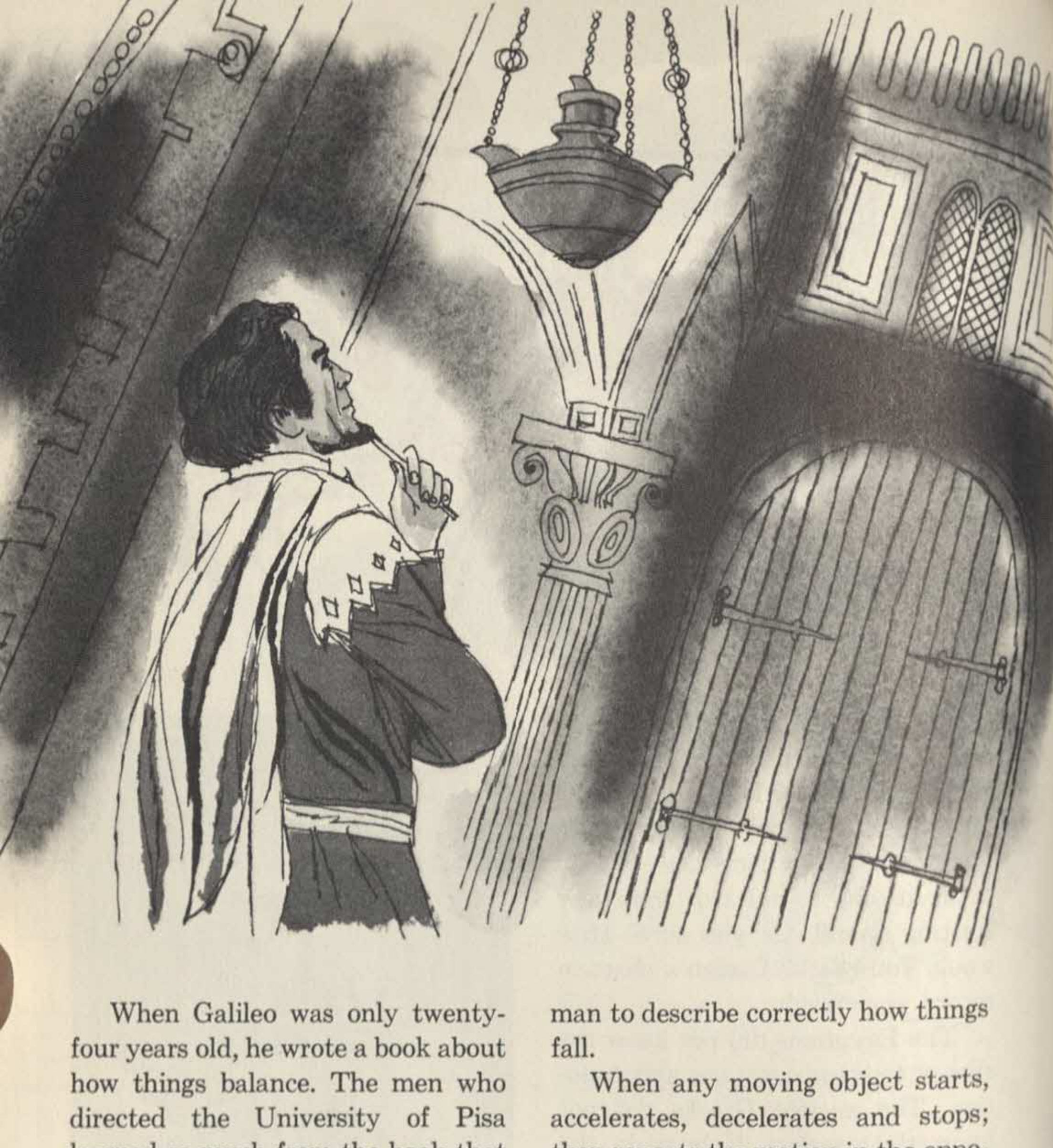
inches above the surface? How long does it take when it starts 3 inches above the surface? How long does it take when it starts 5 inches above the surface? How long does it take to make one round trip from any starting point? Are you sure? How would you check? Design a chart to record your results. □□

The Egyptians did not know the answer to these questions about motion. The ancient Greeks did not know the answers. Nobody in the entire Roman Empire knew the answers to these questions either. Can you think of a reason why? Why is it important that any scientific idea be proven experimentally before it is accepted as being true?

The first scientist to answer these questions correctly was Galileo, an Italian who was born in 1564.



Galileo Galilei



When Galileo was only twenty-four years old, he wrote a book about how things balance. The men who directed the University of Pisa learned so much from the book that they made him a professor. Galileo improved the telescope while he was at the university. With that telescope, he discovered four moons of the planet Jupiter and saw dark areas on the sun's surface called sunspots. Galileo was the first person to realize that our moon is not perfectly round. He was also the first man to describe correctly how things fall.

When any moving object starts, accelerates, decelerates and stops; then repeats the motion in the opposite direction, its motion is said to be *periodic*. The length of time for one round trip is called the *period*.

After you let the truck start to coast down the track, when did it move most rapidly? When did it move most slowly? When was the truck accelerating? When was it decelerating? Is the truck's motion periodic?

COMPARE

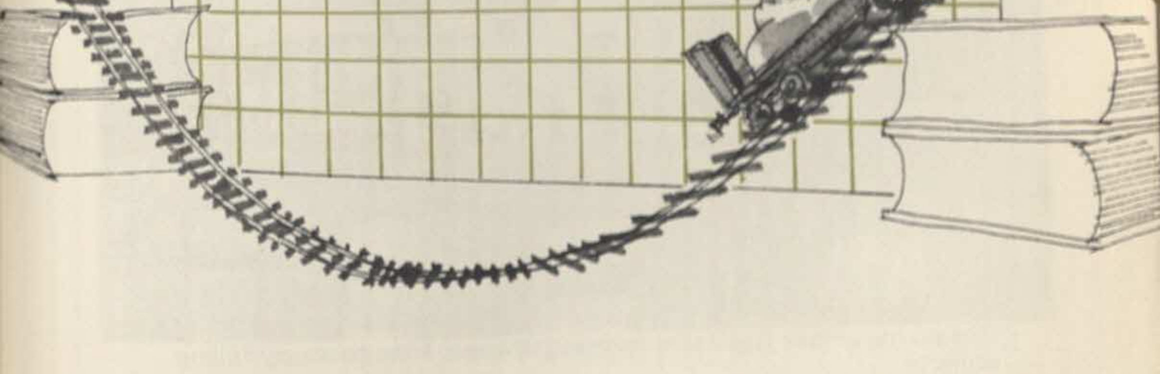
Obtain some modeling clay to change the weight of your model railroad truck. Choose a piece of clay that is just as heavy as the truck. Then, when you use the clay as a weight, the truck and the clay will weigh twice as much as before. Be careful not to get clay on the wheels.

Let the weighted truck go down the track from a height of 6 inches. How long is its period? How does this compare with the period of the unweighted truck released at the same height? Let the weighted truck go from a height of 3 inches. What is its period now? What effect does the weight of an object in periodic motion have on the period? Do you think you can make the truck go higher than the starting point without your pushing it? □□

As you discovered in your activities, all objects fall at about the same rate. The little difference in the speed of falling bodies is caused by the friction between the falling bodies and the air. If there were no air, all bodies would fall at the same rate. This was a very important discovery that Galileo made; until this time everyone thought that the heavier an object was, the faster it would fall.

Stop a moment and think about that idea. Does it sound reasonable? Just thinking about it, you would certainly *think* that a heavier object would fall faster than a light object. Galileo found, by experiment, that it doesn't.

Instead of using reason alone to find an answer, Galileo designed experiments to check his thinking.



Galileo may have used this famous tower in Pisa to study falling objects.

Galileo found that all objects fall at the same rate regardless of their weight. With this single breakthrough, of combining reason with experiment, science greatly increased the growth of civilization. What advantages are there to this method?

It is difficult to imagine civilization progressing at the rate it has without modern science. From earliest times, man observed the world, often very carefully. At times, however, his many superstitions prevented him from understanding the natural causes of things. When he observed the world carefully and with honesty, he was acting even then as a scientist. Man's reason led him to detailed explanations of his observations. The Greeks over three thousand years ago did very well with this kind of science. Civilization progressed, and science progressed along with it. But it was reason, coupled with experiment, that provided the basis for a new and better science. This new science used measurement to support the observations that were being made.

Galileo has been given credit for this great change in science, because he tried things out to check his thinking. He made many careful measurements. In addition, he looked for relationships between his different measurements. Some people say that with Galileo and his experimental method came the birth of modern science.

Measuring Speed and Velocity

How do you measure the speed of an automobile? How would you measure the speed of a bicycle or the speed of an airplane? How do you measure the speed of a ship? How would you measure the speed of a mouse? How would you

One way of measuring speed is in miles per hour.

measure the speed of a snail? Make a list of all the ways you can think of to measure speed.

IMAGINE

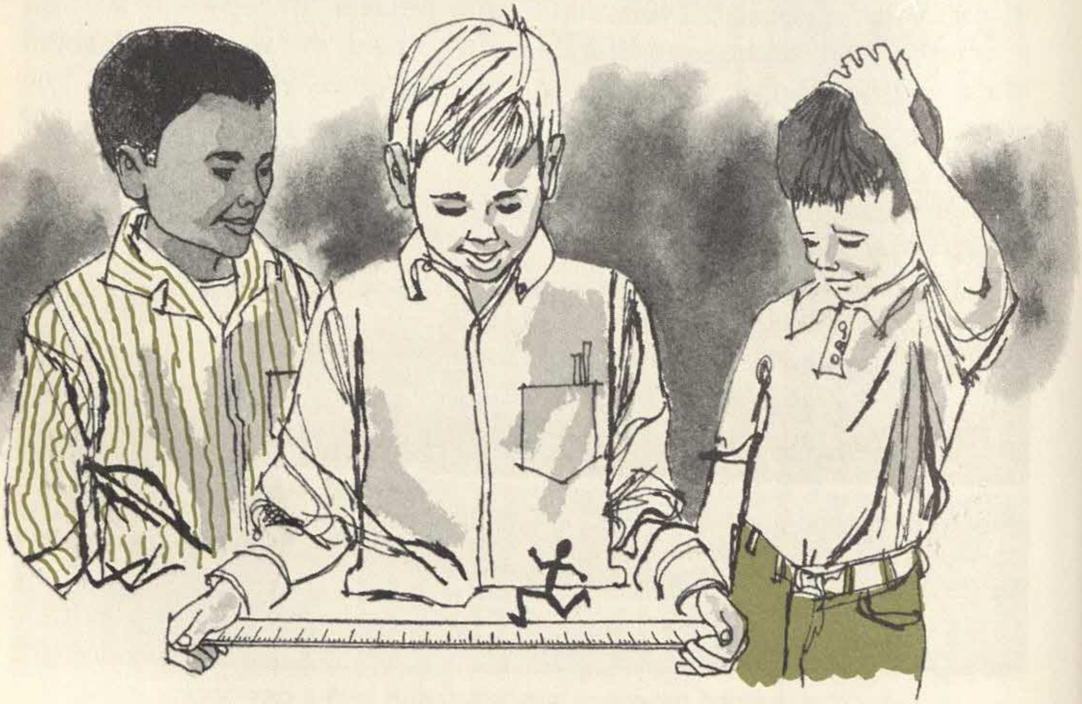
Pretend a little man lives in the rear corner of your desk. Make up a name for him. He is going to help you with the activity.

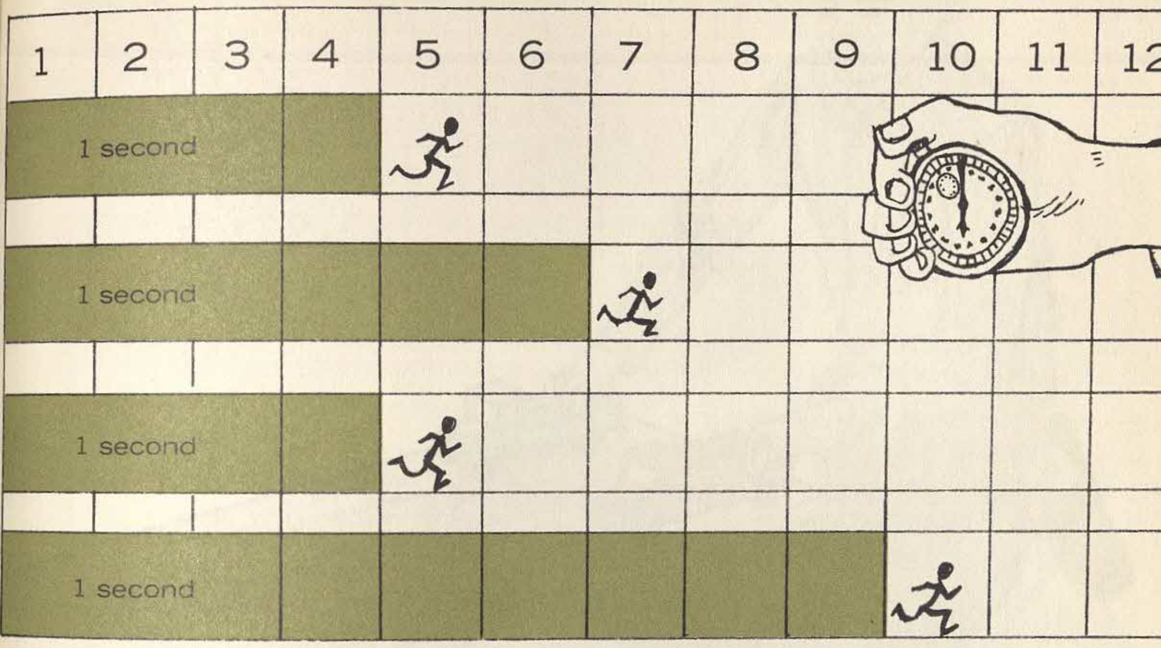
Obtain a ruler or a yardstick. Make believe the little man is standing on the end of your ruler. Now he is running down the ruler. He gets to 6 inches and stops. It took him 6 seconds to run 6 inches. What was his speed? Now he runs 3 more inches, all the way from 6 to 9 inches in 1 second. What was his speed this time?

Start over. The little man is back at the end of the ruler. He is walking this time, all the way to 12 inches, and it takes him 1 minute. Is it correct to say that his speed was 1 foot per minute? Would it be correct to say that he is going 60 feet an hour? Can you think of another way to express the little man's speed?

Science, Imagination, and Experiment

Do you think it is silly for a science book to use a make-believe man living in the back corner of your desk? Most scientists would not think so. In this case, the little man stood for any object. For instance, you could have put a marble at the



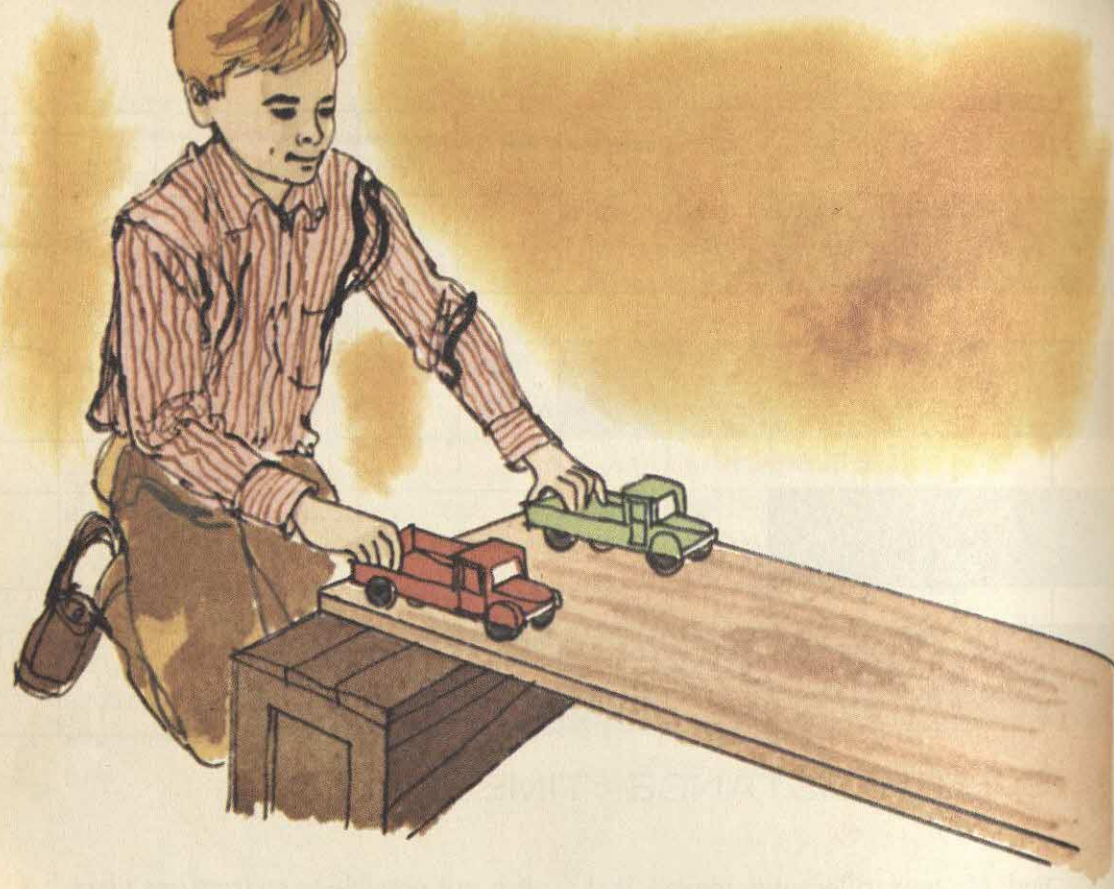


SPEED = DISTANCE ÷ TIME

end of your ruler and moved it 1 inch every second for 6 seconds. When you were asked how fast the marble moved, you could have said "It moved at a speed of 1 inch per second." But you did not have to do the experiment in order to know the answer. You can sometimes do an imaginary experiment. That is why it was all right to invent the little man.

There is nothing wrong in using imagination in science. Do you think it is a mistake to imagine things which seem impossible? Would it be a mistake to imagine a little man going from one end of the ruler to the other in no time at all? To many people, that would be magic, because it is not possible to go from one place to another without taking some time. What do you think?

In some experiments, it is necessary to imagine that something is *not* there as long as you make sure that you tell *what* you imagined. For instance, in the activity that involved coasting a model railroad truck down a grade and up the other side, it would be all right to say, "Without friction and air resistance, a truck would continue in periodic motion on the track until stopped by some outside force." As long as you tell what is real and what is imagination, you are being honest, and in looking for truth, you must always be honest.



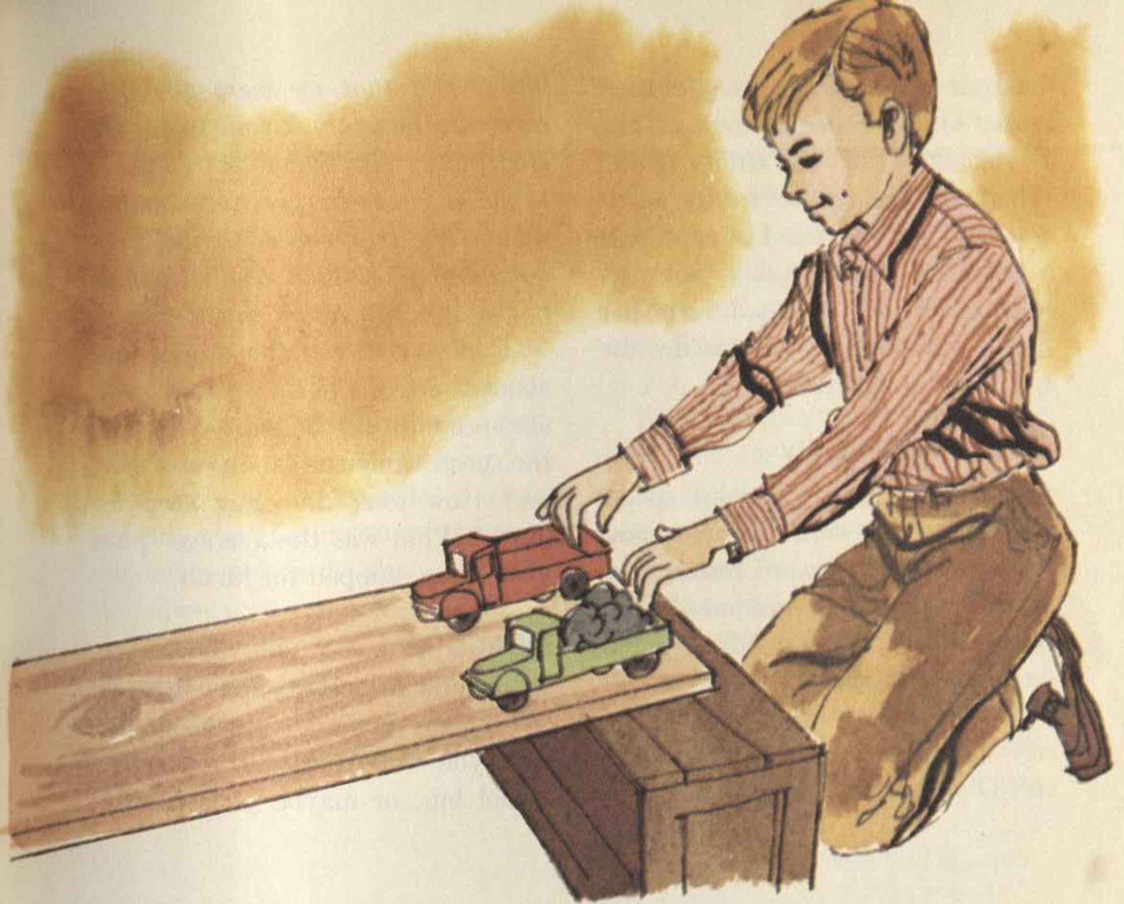
Here is the description a student wrote about an experiment he did. Read the description and tell what you think of it.

"*I took two toy dump trucks and put them on the top of a slanted board, which was two feet off the floor. I let them go at the same time. They both reached the bottom of the board at the same time and then coasted for about the same distance. From this evidence, I decided that they both had about the same amount of friction. I then loaded one truck with the weight of clay that was equal to the weight of the truck. I let both trucks loose from a height of two feet again. The truck with the load of clay got to the bottom of the slanted board before the empty truck and coasted almost twice as far. I think that it would have coasted exactly twice as far except that the weight of the clay made the wheels a little harder to turn.*"

What do you think about this boy's description? How would you check his results?

Here is a description of another experiment. Is this good science?

"*I took two toy dump trucks and filled one with clay until it weighed twice as much as the other. I let them both go from the top of a slanted two-foot board at the same time. The loaded truck didn't go as*



far as the empty truck. I think both trucks should have gone the same distance except something, I don't know what, went wrong."

Did either student come to a correct conclusion? How could you find out which student was correct? Could both students be correct? Could both students be mistaken? How far will two objects coast if one weighs twice as much as the other? Does the weight of an object make it go down hill faster? How can you check your answers?

The only sure way for you to find the answers to these questions is to do the experiment yourself. When you read about an experiment of another scientist, and you do the same experiment the same way and get the same results, you *confirm* the other scientist's conclusions.

Why is it important to do the experiment over again exactly, according to the other person's directions?

CHECK

Repeat the students' two experiments with the toy dump trucks. As you do the experiments, try to answer these questions. How far did the loaded trucks travel? How far did the empty trucks travel? How long did each trip take? Can you

determine the average speed of each loaded truck? Can you find out the average speed of each empty truck? When did the empty trucks accelerate? When did the loaded trucks accelerate? When did each truck decelerate? Which truck had the higher speed? How might you measure the speed of the trucks?

Speed and Velocity

When we use the word speed, we must make sure that we know *exactly* what this word means. Before we define the word *speed*, consider this report turned in by a sixth-grade student.

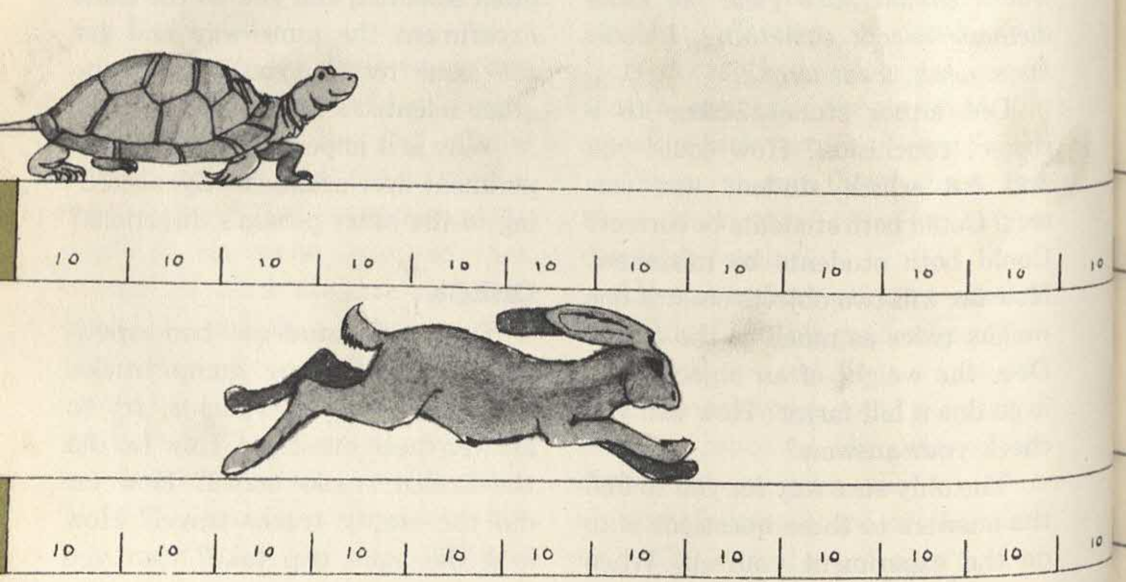
"*We went to see my aunt in the city last week. We drove in our new car. Our car will go very fast. My father said that we were going 60 miles an hour the whole trip. We stopped to eat lunch on our way. I had a cheeseburger and a milkshake. The trip was 180 miles from home to my aunt's house. It took us four and a half hours to get there.*"

Can you answer these questions about the trip? What was the average speed during the trip? What was the speed while the family was driving? How long did they stop for lunch? What was the average speed while they stopped for lunch?

MEASURE

Here is an activity for you to do on the way home from school. Perhaps you walk, perhaps you ride a school bus, or maybe your parents

AVERAGE SPEED = TOTAL DISTANCE



bring you home. How you get to and from school will make a difference in your results, but the activity is the same.

First, find out how far it is from school to your home the way you usually go. You can ask the school bus driver, your parents, or better yet, you can measure the distance yourself. If you walk, you can count your steps and measure how far you go in one step. If you ride, you can find out what the distance meter on the dashboard reads when you start and when you complete the trip.

Second, find how long it takes you to get from school to your home. There are several ways to measure time. If you have your own watch, you have no problem. If not, it is just as good to look at the clock when you leave school and then look at the clock when you get home, and calculate the total time. Why must both clocks be accurate?

Now, try to answer these questions. What was your *average speed*? Do you know your *maximum speed*?

Here are the results some students got for that activity. Raymond had an average speed of 44 feet per second. How do you think he traveled?

Milton had an average speed of 44 feet per hour. How did he probably travel? Did he hurry home?

Peter had an average speed of 150 miles an hour. Do his results seem reasonable to you? Explain your answer.

In your class, who had the highest average speed? Who had the lowest average speed?

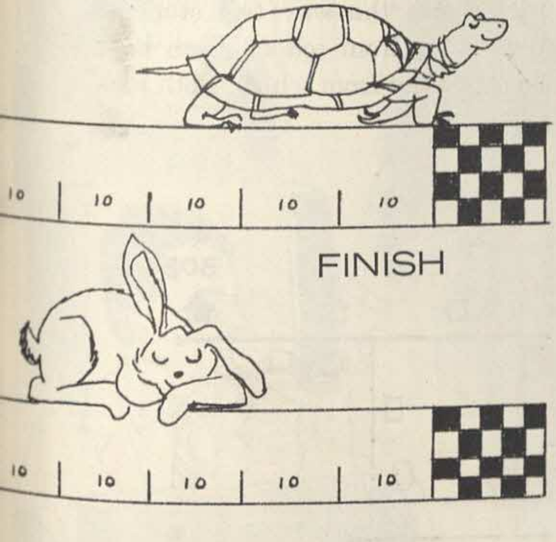
Do you remember the fable of "The Tortoise and the Hare"? In that story, which character had the highest *average* speed? Which had the highest *maximum* speed?

Time can be measured in seconds, minutes, hours, days, weeks. It can also be measured in months, years, and centuries.

There are other ways of measuring time. Do you know them? Do you know how time is related to motion?

Distance can be measured in millimeters, inches, yards, meters, miles, and in many other ways.

÷ TOTAL TIME



Speed is measured in units of distance traveled in a certain amount of time.

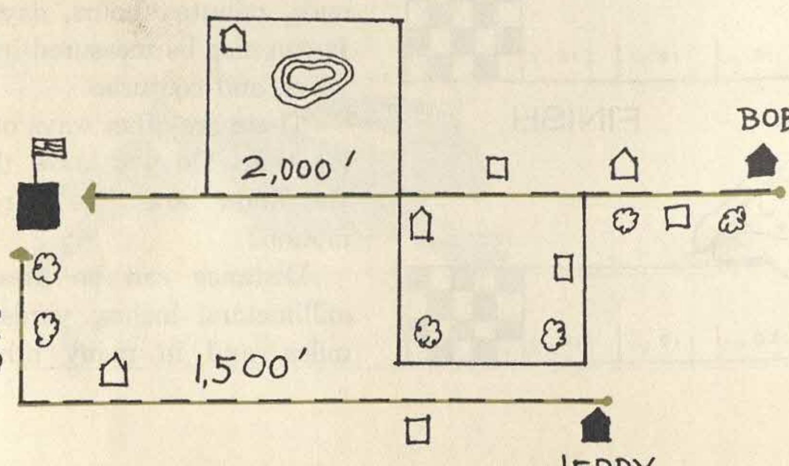
Make a list of all of the ways that you know of measuring distance. All of the names on this list and on your list are *units of distance*. Do you know the meaning of the word "units" when it is used like this? What is a unit of time? What is a unit of distance? Can you name a unit of weight?

SPEED

Speed is always measured in distances traveled in some unit of time. Which are speeds in the following list: inches per second, miles per day, feet per year, yards per year, meters per month, years per century? Can you think of other examples of speeds?

Some speeds are measured in special terms. For instance, the speed of ships and modern jet aircraft is commonly measured in knots. A knot is one nautical mile per hour. How long is a nautical mile? Why is it wrong to say, "knots per hour"?

The map at the bottom of this page shows the way two students went home from school. Both boys live 2,000 feet from school. Both took



30 minutes to get home. What is Jerry's average speed? What is Bob's average speed from school to home? How is it possible for both boys, with different average speeds, to travel home in the same time?

PROBLEM

A man is riding across the continent on a railroad train. The train is going west at 70 miles an hour. The man is in a coach near the front of the train and decides to go back to the dining car. The man walks at a speed of three miles per hour. Which way is the man moving? How fast is he moving? After he has finished eating, the man walks back to the front of the train again at three miles per hour. Now, which way is he going? How fast is he going now? □□

How fast are you going right this minute? How fast is the earth revolving? How fast is the earth rotating? Is the entire solar system in motion? What must we know before we can say how fast we are moving?

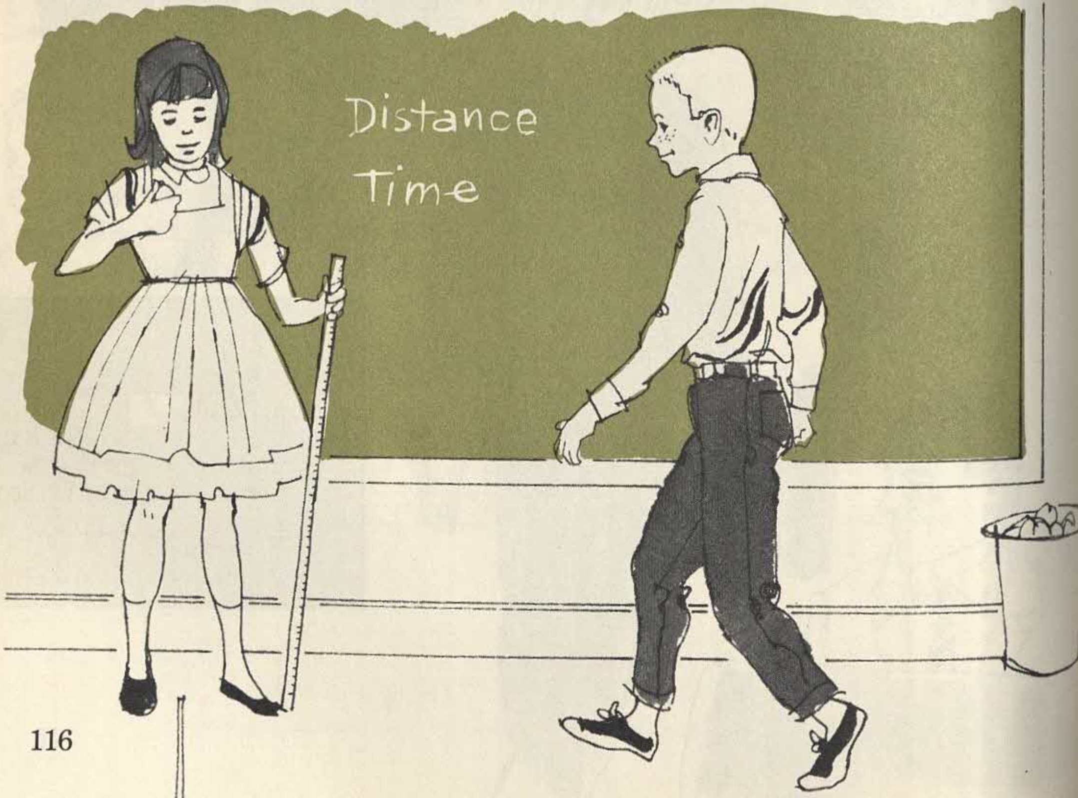
VELOCITY

When scientists use words, the words must have a meaning that is understood to be the same by everyone who uses or reads them. So, when you use the word *velocity*, everyone must agree that you are talking about the rate something is moving in a known direction. Since velocity includes rate, it has a distance and a time. Every velocity is expressed as a distance traveled in a unit of time in a given direction.

A train going 45 miles an hour covers a distance–45 miles, in a time of 1 hour. This is the rate of travel or speed of the train. When the direction of the train is known, however, we call it velocity. An automobile travels north a mile a minute. What is the distance? What is the unit of time? How far would the car go in an hour? How far would the car go in a day? What is the velocity of the automobile?

MEASURE

Use a yardstick or a ruler to measure the distance from the front to the rear of your classroom along the floor. Now walk slowly from the front of the room to the back. At the same time, have someone measure the time it takes you. You have covered a certain distance in a certain time. Write down your distance and time as a velocity. Is this a good way to express velocity? When is it best to use miles per hour? When is it best to use feet per second? Could you express your velocity as inches per day? □□



Would it be wise to use just one unit of distance and just one unit of time to measure the velocity or the speed of everything? Would you want to have just one unit of distance and one unit of time? Why?

If we wish to be exact when we talk of velocities, we must consider three things: a distance, a unit of time, and a direction. What are four very important directions? In which direction would you travel to get from where you are now to the Capitol Building in Washington, D. C.? Which direction would you follow to get to London, England? Is it possible to go in any other direction and still get to London?

An airplane travels from Atlanta, Georgia, to San Francisco, California. The plane takes five hours and thirty minutes to make the non-stop trip. What else must you know to give a description of its motion?

Sometimes you can save time and effort by giving the average speed for a long trip, rather than by telling about a lot of unimportant bits of motion. For example, when a car drives four miles at 60 miles per hour, then 10 miles at 30 miles per hour, and finally 12 miles at 20 miles per hour, you can say that the car was driven 26 miles at an average speed of 26 miles per hour. The average speed is defined as the total distance divided by the total time.

This can be written: $\frac{\text{Total Distance}}{\text{Total Time}}$

What was the total distance that the car traveled? How long did it take for the car to travel 4 miles at 60 miles per hour? How long did it take the car to travel 10 miles at 30 miles per hour? How long did it take the car to travel 12 miles at 20 miles

Moving objects often speed up, slow down, and change direction many times.

per hour? Add all of your answers and change the total number of minutes to hours. How many hours did it take for the car to complete the trip? Do you see now why the average speed was 26 miles per hour?

If the details of the trip are not important, it is unnecessary to give the individual speeds and distances. What was the maximum speed in the trip just described?

You have just finished a series of activities concerned with motion, but motion is not always a simple idea to understand. When we talk about motion, we really have to think of a number of ideas all at once. The paths followed by automobiles, bicycles, airplanes, and people, going from one point to another, are fairly complicated. In motions such as these, an object starts from rest, speeds up, slows down, and turns, clearly going through quite a variety of changes. You are used to this kind of everyday motion and probably take it for granted. However, to really understand such complex motion, you will have to study motion further.

A very common way for scientists to study the world about them is to think of *ideal conditions*. What do you think the words "ideal condi-

tions" mean? Would there be friction under ideal conditions? Would there be any resistance from the air under ideal conditions? How far would an object go, moving at a velocity of 88 feet a second, under ideal conditions? How fast would the object be going after ten years had passed?

In answering these questions you must understand that as long as a moving object is not going up or down, gravity will have no effect on that object. Therefore, it is unnecessary to assume that there is no gravity in order to have an ideal condition in this case. Even though you may *say* that under ideal conditions an object would continue in motion forever unless stopped, you will never be able to find such ideal conditions on the surface of the earth. As you study the motions of simple objects, friction and air resistance will always be getting in the way. Using the idea of ideal conditions means that you figure out, or decide, what would have happened if friction and air were not involved. To see what this means, try the following activity.

EXPLORE

For this activity you will need a friction cart or a model railroad flat car. You will also need about a yard of track, including at least one piece of curved track, and also several marbles.

Place the flat car on the track and put a marble on it. If you are careful, you will be able to balance the marble on the flat car so that it does not roll off. Now, give the flat car a push. What happens?

Put the flat car and the marble back where they were. This time, start the marble and car in motion by lifting up on the end of the track very gently. After they are moving, put out your finger and stop the flat car. Describe what happens. Be careful not to knock the car off the track. If the car should fall off the track during these activities, start over again.

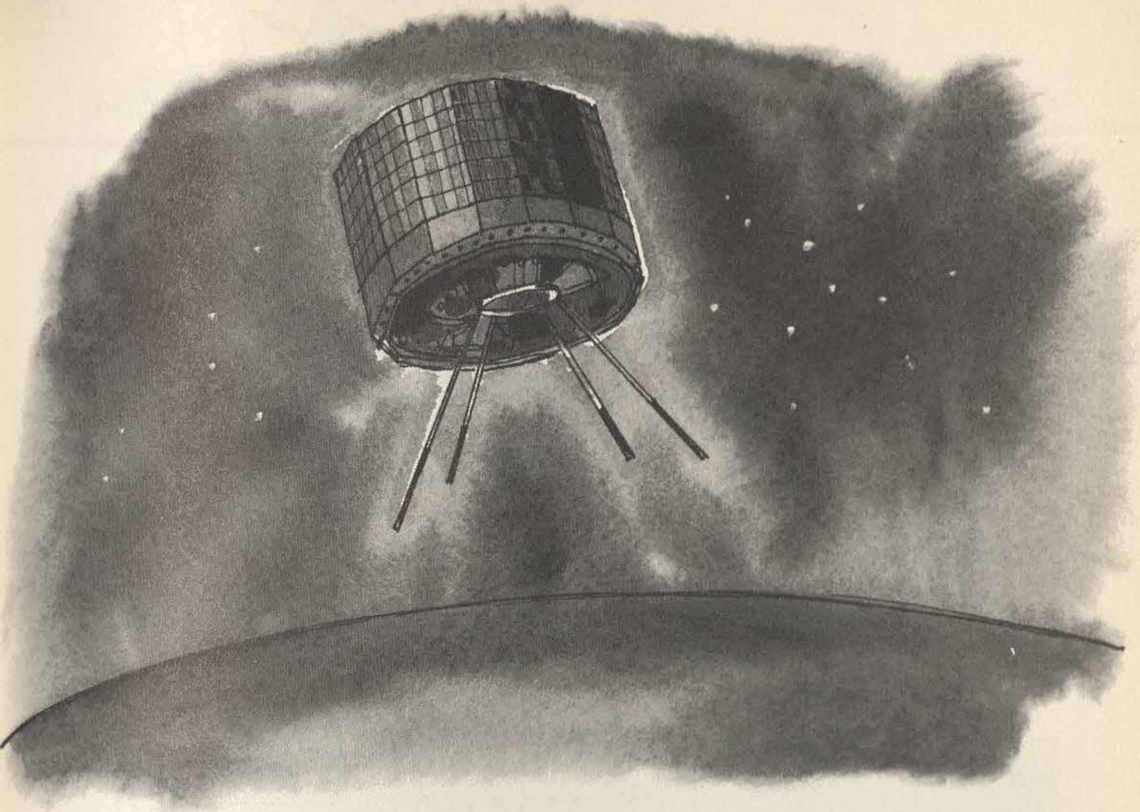
Scientists believe that an object will not move unless some force acts on it. They also think that a moving object will continue to move at the same speed and in the same direction, unless some force stops it or changes its motion. What evidence have you found concerning these statements? Do you think these statements are true? Do you know of anything that continues to move without any help?

Sir Isaac Newton

Newton's First Law of Motion

Have you ever heard of Sir Isaac Newton? Newton was the man who discovered the law of gravity. Sometimes people say that he discovered gravity. This is not an accurate statement. As long as man has existed, and probably since the beginning of time, there was gravity. What Newton did discover was that all objects in the universe seem to be attracted to one another. The attraction depends on the size of the objects and the distance between them. This discovery has been called the law of gravity.

Sir Isaac Newton was born in England on Christmas Day in 1642. He studied at Cambridge University, where he was awarded a Master of Arts degree in 1665. Soon after his graduation a plague struck England and many people died. Newton went to live in the country to avoid the plague. During the two years that he lived in the country, he not only did his famous work on gravitation, but also discovered that white light is composed of light of differ-

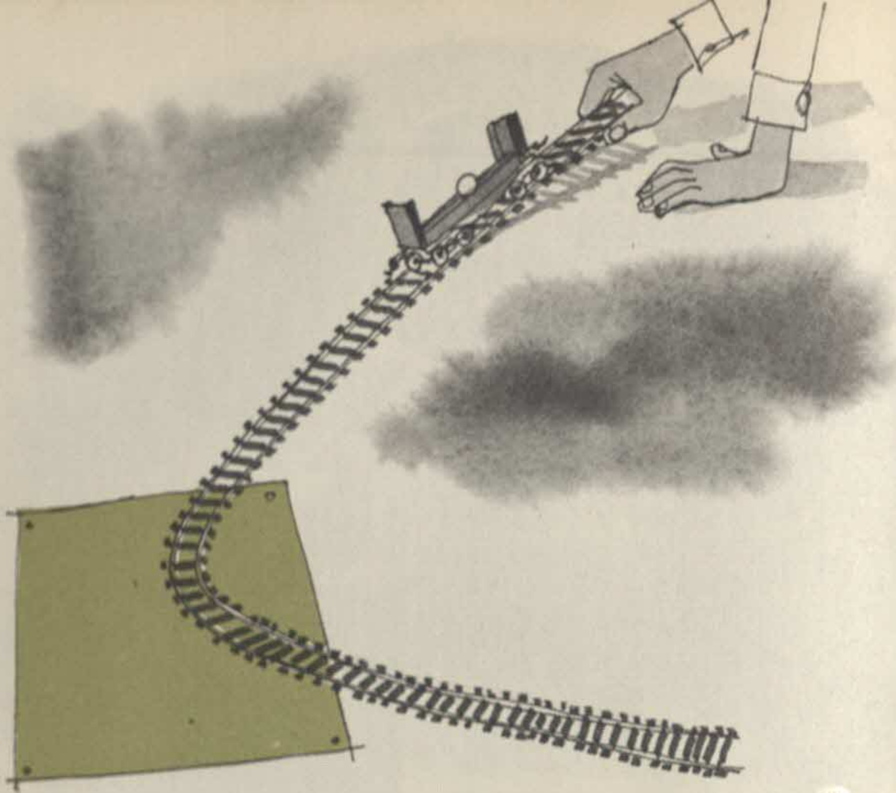


ent colors, and laid the foundation for calculus, a branch of mathematics. Newton was elected to Parliament, was knighted by Queen Anne, and was made president of the Royal Society, the most important science organization in the world at that time. He held this position for twenty-five years.

Newton, one of the greatest scientists who ever lived, also discovered much about motion. He tried to put together all of the important ideas that man had learned about motion into a few statements. These statements have been called the laws of motion. There are only three of these laws, but they represent one way of explaining all moving objects anywhere on earth or in space. It was because these statements were believed to be true anywhere in the universe that they were called laws. His First Law of Motion states:

A body at rest or in uniform motion will remain at rest or in uniform motion unless some external force is applied to it.

What did Newton mean when he said, "uniform motion"? What evidence do you have that the First Law of Motion may be true? Can you restate the First Law of Motion so that the effect of friction is included in it? Do you think a rocket can move forever?



INVESTIGATE

Connect several pieces of track. The curved track should be in the middle as shown in the picture. Place the flat car on the track, and the marble on the car, as you did before. Gently lift the end of the track so that the marble and the car begin to roll down the track. What happens when the flat car comes to the curved track?

If the car goes off the track, replace the car and marble at the starting point. This time, do not lift the track as high. The car should have just enough speed to coast to the end of the track before it stops. What happens to the marble at the curve? Put a sheet of paper under the track at the curve.

Do the activity again. This time, watch the marble very closely. Make a mark on the paper to show the path followed by the marble when it falls off the flat car. Do the activity several times, each time marking the path followed by the marble. Does the marble always follow the same path? Find some other round object to use in place of the marble. Does the same thing happen? When you are riding in an automobile and it goes around a corner, which way do you lean? Why?

Uniform motion means that an object has a constant, or unchanging, velocity. It neither speeds up nor slows down and is moving in a straight line. How would the First Law be used to explain the marble

rolling off the flat car at the turn in the track?

Have you ever noticed signs along the highway like the one in the picture? Why does the State Highway Department put up these signs? What might happen to an automobile if it went around a 45 mile per hour turn at 65 miles per hour? Have you ever ridden in a car along a road with lots of ups and downs? What do you feel when the car goes over the top of a hill? Have you ever ridden in a high speed elevator in a large building? What do you feel when the elevator starts? What do you feel when the elevator stops? If you were standing on a bathroom scale in an elevator, and the elevator started going up, would your weight change? What would happen to your weight if the car were to come to a sudden stop?

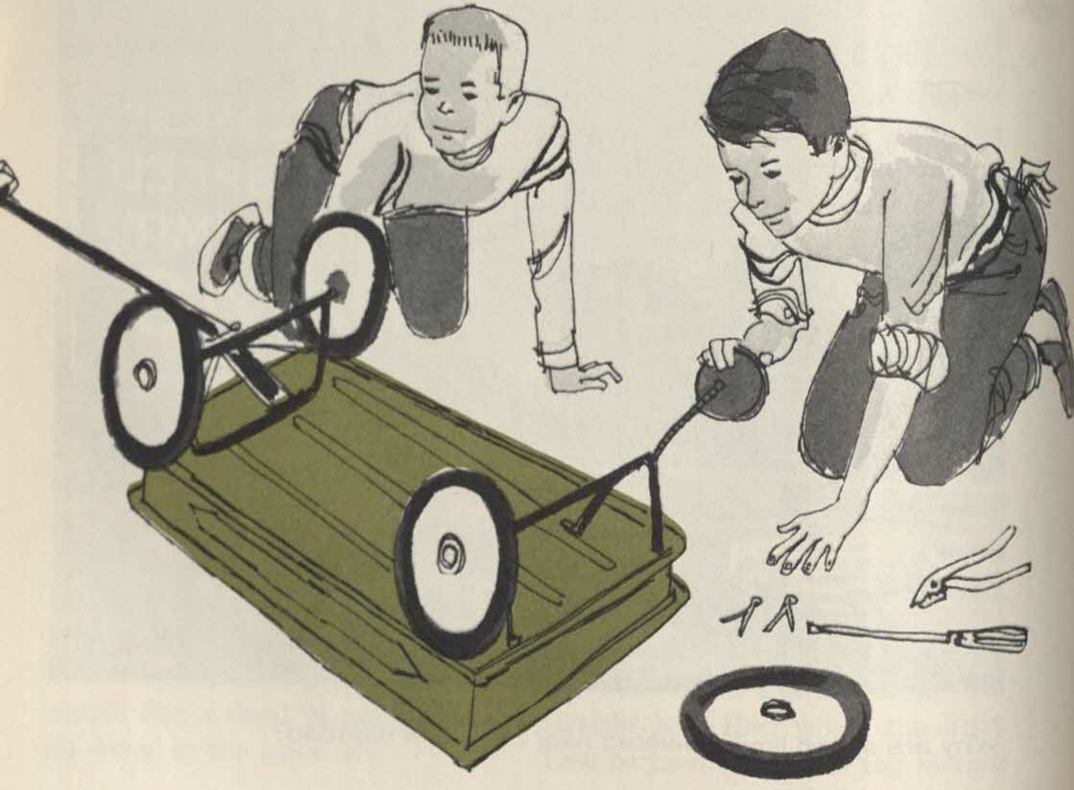
Newton's Second Law of Motion

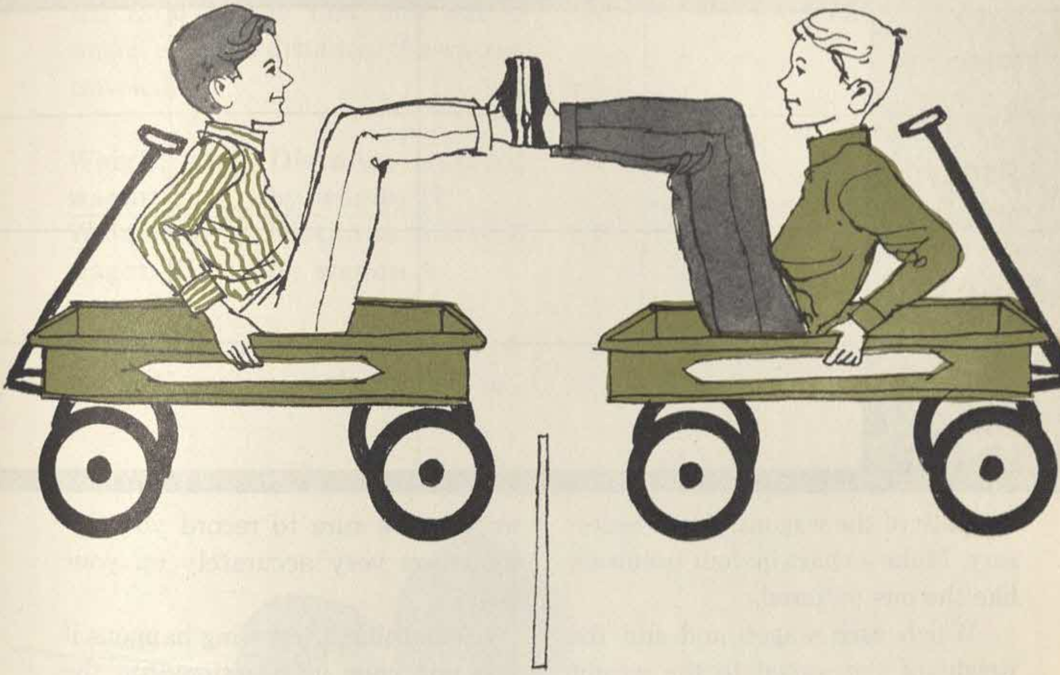
Bring two large coaster wagons to school. If several people bring in wagons, try to match wagons of the same size so that two students can work with two similar wagons. First set up a wagon garage. You will need some axle grease or oil, pliers, hammers, and screwdrivers. A box of cotter pins will come in handy too.

Why are speed limits lowered near curves in the road?

Take all four wheels off each wagon. Carefully clean each of the wagon's axles. Clean the holes in the wheels, removing the old dirt and grease. After the wheels are clean, put a line of grease or oil along the axles before replacing the wheels. Now spin the wheels to test them. Do they run more smoothly now? What effect has the grease or oil on the turning of the wheels?

Put a basketball, a volley ball, or a soccer ball in a wagon. Pull on the wagon. What happens to the ball? Stop the wagon. Now what happens to the ball? Sit in the wagon and have another student give you a push. What do you feel? Sit in the wagon and when you are moving, have another student stop you suddenly. What do you feel? Have two students sit in the wagon, one facing forward to steer, the other facing the rear. Move the wagon close to the wall. The student facing the wall should put both feet against the wall and shove sharply. How far does the wagon coast? Do this several times, pushing just as hard each time. Does the wagon coast about the same distance each time? Why? What stops the wagon?





MEASURE

For this activity you will need another large wagon, as much like the first wagon as possible. It does not have to look like the first wagon, but it must weigh about the same and should slow down at about the same rate due to friction. Think of several ways to compare the friction of two wagons. Test several wagons.

Two students who are about the same weight should sit in the two wagons facing one another, as shown in the picture. Mark the place on the floor that is exactly between the two wagons. Call one, wagon number I. Call the other, wagon number II. Shove! How far does wagon I roll? How far does wagon II roll? Do both wagons roll smoothly? If you do this activity on the playground, there might be stones or dirt on the ground that will keep the wagons from rolling smoothly. Sweep

	WEIGHT		DISTANCE	
	WAGON I	WAGON II	WAGON I	WAGON II
TRIAL 1				
TRIAL 2				
TRIAL 3				
TRIAL 4				

the path of the wagons, if it is necessary. Make a chart in your notebook like the one pictured.

Weigh each wagon and add the weight of the wagon to the weight of each passenger. Fill in the first line of your chart. Now, have two other students who weigh less than the first students sit in the wagons and repeat the activity. Fill in the second line of your chart. Have two students who weigh more than the first students sit in the wagons and again repeat the activity. Fill in line three of your chart. Now have two students sit in one wagon and one in the other and repeat the activity. Fill in line four of your chart. Have the same three students change wagons and repeat the activity again. Fill in the next line of your chart. Repeat this activity a few more times, changing the weights in both wagons. Be sure to record your information very accurately on your chart.

Something interesting happens if you put your information into the following form.

Multiply the total weight of wagon I by the distance it traveled. Do this for each of the different trials with the wagon. Now multiply the total weight of wagon II by the distance it traveled. Do this for each of the trials with wagon II. Put all of your information in a table similar to the one shown. What do you notice about the numbers? What is the relationship between the weight and distance products of wagon I and II? Divide the total weight of wagon I by the total weight of wagon II. Now divide the distance traveled by wagon II by the distance traveled by wagon I. Place the numbers side by

side. Do you notice a regular pattern?

The following formula compares the ratio of the first and second wagon with the distances the wagons traveled.

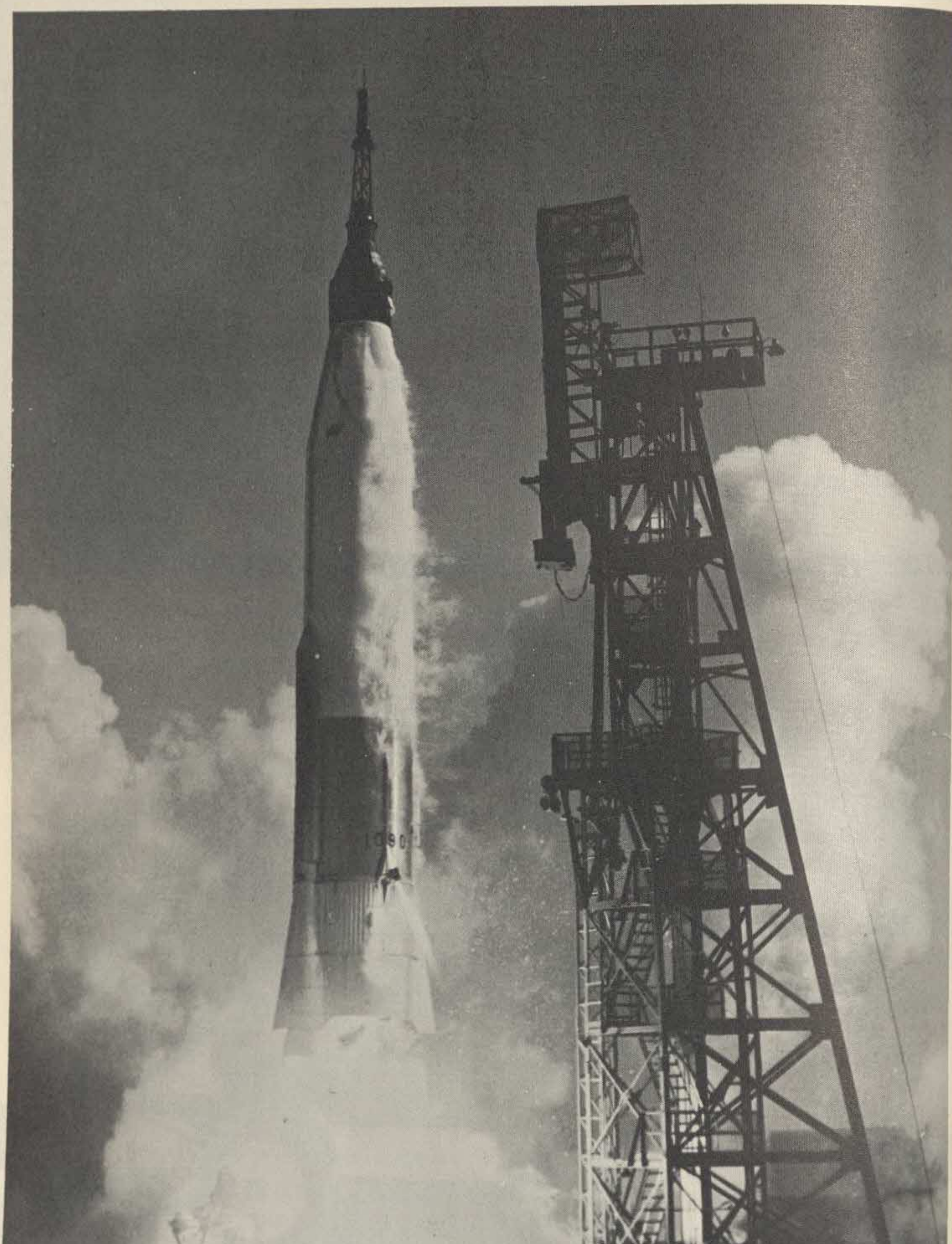
$$\frac{\textbf{Weight of wagon I}}{\textbf{Weight of wagon II}} = \frac{\textbf{Distance traveled by wagon II}}{\textbf{Distance traveled by wagon I}}$$

See if your information supports the mathematical statement above.

Newton's Third Law of Motion

Obtain some heavy objects. These should weigh at least 20 pounds each. You can bring in large stones, a medicine ball, or a cloth bag filled with sand.

Put your heavy objects in the wagon and sit in the wagon yourself. If your heavy objects are the kind that might damage the floor, either cover the floor or work outside in the school yard. Throw a heavy object out of the wagon. In what direction did you move?



What evidence does a rocket provide for Newton's Third Law of Motion?

COMPARE

You can do a similar activity on a pair of roller skates. Stand up on your skates and have a friend hand you a heavy weight. Throw the heavy weight away from you. Which way did you move? Which way did the weight move? Can you think of other examples where a force in one direction causes a motion in the opposite direction? □□

Newton's Third Law of Motion is:

To every action force, there is an equal and opposite reaction force.

What evidence do you have from your activities that this law is true? What evidence do you have that this law might *not* be so? When two students in two wagons pushed against each other, did the force from wagon number I make itself move? Did it cause wagon number II to move? When you threw the heavy object out of the wagon, what supplied the force that moved you?

EXPLORE

Stand up. Jump as high as you can. When you jumped you pushed against the floor with a force. The floor pushed back on the bottom of your feet and you went up in the air. Did the floor move? Are you sure of your answer? When you throw a ball a long way, you have to apply a great deal of force. When you just toss it a little way, you need only apply a little bit of force. If you throw a ball very hard out of a wagon, will you move farther than if you just flip the ball gently? Try it and see.

OBSERVE

Pull an empty wagon. Is it easy to start? Is it easy to stop? Have another student sit in the wagon. Now pull it. Is it as easy to start this time? Is it as easy to stop? Do you know what makes the difference? People agree that the difference comes from a characteristic of all material things called *inertia* (in-UR-shuh). Several activities are described in the following pages to help you understand inertia.

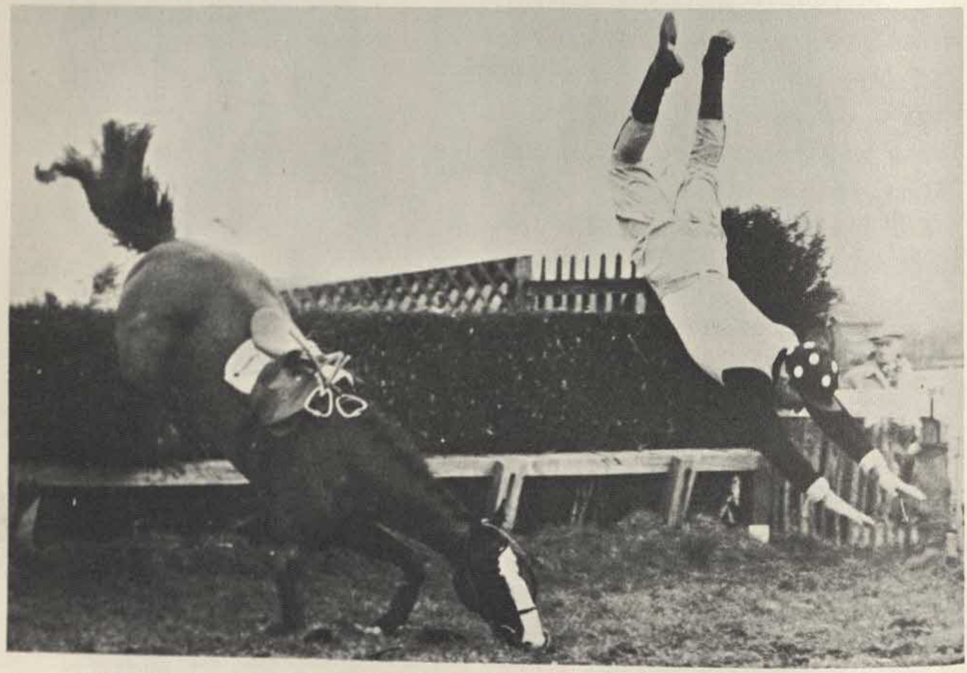
Find an empty cardboard box. Put it on the floor and kick it. What happens? Now, put a heavy stone or brick in the box. Would you kick it now? Why not? When is the box harder to move? Do you know why trucks and buses need bigger brakes than automobiles? Why does it take so long to stop a railroad train? Why does a train start so slowly? Why do you think trains have the right of way at crossings?

EXPLORE

Tie a piece of string around two bricks or a number of books, as shown in the picture. If you use bricks, be careful of your toes. Very gently, pick up the bricks by lifting the string. Does the string break? Start over again. This time give the string a sudden jerk. Does the string break? Try to explain these results. Do bricks have inertia?

ACTIVITY

Hang several books from the edge of your desk as shown in the picture. Slowly pull on the lower string until one of the strings breaks. Which string breaks? Hang the books back up as before. This time give a quick yank on the string. Which string breaks this time? Do this activity several times. Does the same string break every time? Try to explain what happened in this activity using your own words.



How does this picture provide evidence for the inertia of moving objects?

ACTIVITY

Place a plastic glass full of water on a sheet of paper on the edge of a table. Hold one end of the paper in your left hand. Hit the middle of the paper as hard as you can. What happens?

EXPLAIN

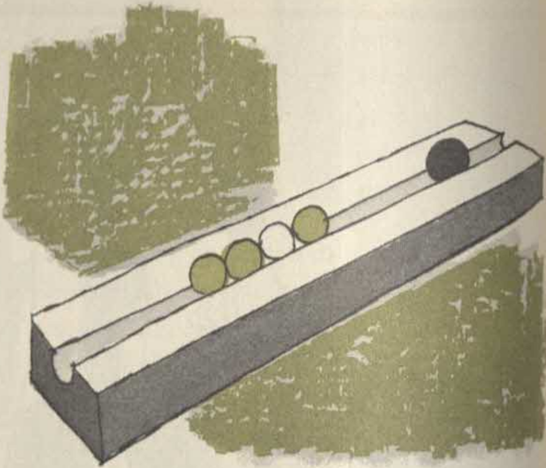
Find two paper bags that look alike. Blow up one bag so that it appears full. Put heavy books in the other bag. Mix up the bags until no one knows which bag has the books and which bag is empty. Have another member of the class pick up one bag in each hand just as quickly as he can. What happens? Why? Does the word inertia make this activity easier to explain?

Sometimes a magician on television or in a theater will pull a tablecloth out from underneath a full set of dishes. Is it really magic? Can you explain how the trick is done?

Place a coin on a card on top of an empty glass. Snap the card out from under the coin with your finger. Where does the card go? Where does the coin go? Explain what happened.

ACTIVITY

Do liquids have inertia? Stir a glass full of water. Does the water continue to go around after you stop stirring? Why? Allow a glass of water to remain still. Suddenly twist the glass. Does the water move when



the glass moves? Why is it so difficult to carry a shallow bowl of soup without spilling it? What happens to the soup when you begin walking? What happens to it when you stop?

OBSERVE

Stand on a bathroom scale. How much do you weigh? Bend over suddenly. What happens to the scale? Stand up suddenly. What happens to the scale? Hold a heavy weight while you stand on the scale. What happens when you lift the weight suddenly? What happens when you suddenly lower the weight? Can you explain what happens?

Obtain a model railroad flat car and a short piece of track. Place the flat car on the track and add a weight to the car. Put your fingers on both ends of the track. Now push the track back and forth between your two hands. What happens? Does the flat car move? Explain what happens. Does the same thing happen when the flat car is not weighted? Are there any differences? Why?

Momentum

ACTIVITY

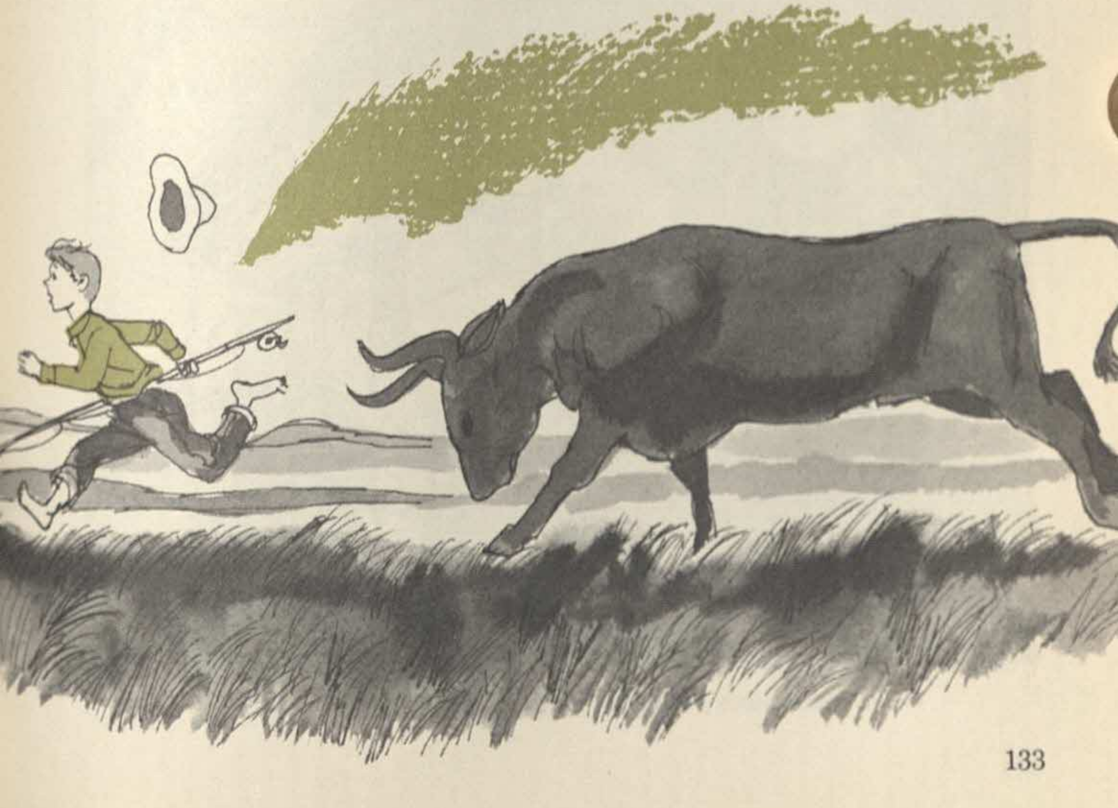
Set up a long board with a groove in it and a row of marbles. The illustration shows how the grooved board should look. You will also need a grooved hill placed next to the long board, as shown in the picture.

Release one marble so that it rolls down the hill and hits the row of marbles. How many marbles start to move apart when the first marble hits? Release two marbles at the same time so that they roll down the

groove together. How many marbles move apart when two marbles hit? Can you predict what will happen if you let three marbles roll down together? Try it and see if you were right. What do you suppose would happen if you let two marbles roll down the hill and let them hit just one marble? What would happen if you let one large marble hit two small ones? □□

The marbles in this activity represent things that bump into each other. It has been found that colliding bodies seem to obey a set of rules. In order to explain the action of the colliding objects, it is very helpful to use a single word that stands for the amount of material (an object's mass) multiplied by its velocity. This word is *momentum.*

Can you imagine a boy being chased by an angry bull, with both of them running at the same velocity? You might at first think that their motion is the same, but there is a very important difference. If they should both run into a barn door, each of them will affect the door differently. The boy will probably bounce back without changing the barn door very much. The bull, on the other hand, has an excellent chance of crashing down the door. This happens because the bull has a different "*amount*" *of motion* (momentum). The momentum of any moving body is a product of *two*



things, the velocity and the amount of material (bulk) in the moving body. This amount of material is called the object's *mass*. Anything that occupies space has an amount of mass. The mass of an object never changes. You are most familiar with an object's *weight*, which is the pull of gravity on an object's mass. When the pull of gravity becomes less, the weight of a particular mass becomes less. When the pull of gravity is greater, the weight of a mass increases.

On the moon, the weight of an object is less than it would be on earth. The mass, however, remains the same. On a larger planet, where the gravity is greater than on earth, the same object would weigh more than it does on this planet. The mass does not change, because the amount of matter remains the same. It is possible for any mass to become absolutely weightless when the effects due to gravity are removed. This happens to astronauts during their trips in outer space around the earth. The astronauts are "weightless," but they can never be "massless."

Momentum depends on this idea of mass. To find out if an object has more mass than another, both objects must be placed on a balance. It would take many boys to equal the mass of one bull. This means that the mass of one bull is much greater than the mass of a single boy. If it

Weightlessness experienced by astronauts in training.

takes 30 boys to balance one bull, then the bull has 30 times as much mass as one boy. When both are running with the same velocity, the bull has a far greater momentum. Do you know why?

Momentum can be written mathematically as $M = mv$, where M represents momentum, m represents the mass of the moving object, and v is the velocity of the object.

How might a small mass have a high momentum? How might a large mass have a low momentum?

If mass is measured in pounds, and velocity in feet per second, then momentum must be measured in foot-pounds per second. If mass is measured in ounces and velocity in inches per second, how would momentum be measured?

Work and Motion

To a scientist, work is force times distance. A force can be defined as a push or a pull. How do you measure force? Is an ounce a force? Do you recall the many ways to measure distance? Refer to your list of several different ways to measure distance.

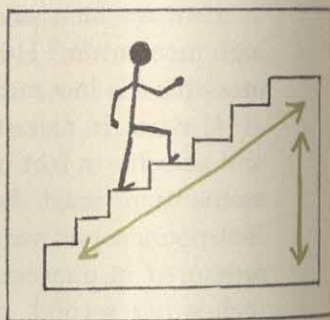
It is easy to calculate the amount of work that you or anything performs, when an object is lifted up against the pull or force of gravity. All that is needed is to measure the vertical (up and down) distance, and the weight of the object. Multiplied together, these two figures give the work done.

ACTIVITY

Obtain an object that weighs one pound. A new box of chalk sometimes weighs one pound. Many things in a grocery store come in one-pound packages. Now measure the distance from the top of your desk to the floor. Put the one-pound object on the floor. Lift the object from the floor to the top of your desk. How much work did you do? How much would you have done if you had lifted the one-pound weight 10 feet? How much work would you have done if you had lifted the one-pound weight 100 feet?

Hold the one-pound weight in your hand. Do not lift it, just hold it in your hand. Are you doing any work? Are you exerting any force? Is the weight moving any distance? What two things must happen if any work is to be done?

BOY'S WORK = BOY'S WEIGHT × HEIGHT OF STAIRS



ACTIVITY

Place the one-pound weight on the top of your desk or table. Measure the distance from one side of your desk to the other. Now pretend that you are able to slide the weight across the desk without using any force. Is any work done when no force is used? Now slide the weight across the desk. In which direction does the one-pound weight exert a one-pound force? In which direction did you move the one-pound weight? Did you exert less force in moving the object from one side of your desk to the other? How might you measure this force? Is it easier to move a weight this way?

ACTIVITY

You can show how much work is involved in climbing stairs. Write your weight down on a sheet of paper. Bring the paper with you to a flight of stairs. Now measure the distance from the floor to the top of the stairs. The picture shows two ways to measure this distance. Which way do you think is correct? Why?

Climb up the stairs. How much work did you do? Each student should calculate the amount of work he did when he climbed up the stairs. Who did the most work? Who did the least amount of work? Do you know why?

PROBLEM

Two men have jobs in a flour mill. One man carries 100-pound sacks of flour from a pile and puts them in a freight car. He has to carry the 100-pound sacks of flour 50 feet. While the man carries the sacks, he does not move them up or down. The other man carries the same sacks of flour from the basement up to the first floor (a distance of 10 feet) and puts them in the pile. Which man does the most work? Why?

MEASURE

To find the amount of work done when an object is moved horizontally, you must measure the amount of force needed to move the object, and the distance the object is moved. One way to measure the force needed is to use a spring scale. The picture shows how a spring scale can be used to measure work done horizontally.

For this activity you will need a spring scale. Do what is suggested in the picture, and calculate the amount of work you do. What two

things are important in determining the amount of work done moving an object horizontally?

Hook or tie one end of a spring scale to something that will not move. Pull on the spring scale. How much work are you doing? Why?

Look again at the table of data you collected when you studied friction. If you have mislaid your table, do the activity over again.

How much work was done when a 10-crayon load was pulled a distance of 10 inches across the surface of your desk or table? Must you weigh each crayon? How much work was done when a 7-crayon load was pulled across a waxed paper surface? Calculate the amount of work done when each load was pulled across each surface. When was the most work done? When was the least work done?

Potential Energy and Motion

When a paper box of crayons pulled a load across the top of your desk, the falling weight did the work. Any object which can fall or roll, or otherwise get closer to the center of the earth than it is, has the ability to do work. There is a word that means the ability to do something if given a chance. That word is *potential.*

A body that is able to move down has the *potential* for doing work. How much potential work could a 1-pound object on the top of your desk do? If a 100-pound rock fell over the edge of a 100-foot cliff, how much potential work could it do? Potential to do work is often called *potential energy*. We can think of energy as "the ability to do work." How many different forms of energy can you name?

ACTIVITY

Stand on top of a chair or table. How much potential energy do you have? If you stood on the same chair or table and there was a 5-foot hole in the floor that you could jump into, how much potential energy would you have then? Potential energy is sometimes called "energy of position." Can you explain why?

Power

Power is the rate at which work is done. Power can be measured as the amount of work done in one second. Place a 1-pound object on the floor beside your desk again. Lift the object from the floor to the top of your desk in one second. If your desk is 2.5 feet high, your power was 2.5 foot-pounds per second. You can calculate the amount of power put out by multiplying the weight of the object and the distance the object was lifted, and then dividing this product by the time needed to lift the object. The mathematical sentence looks like this:

$$\frac{\textit{Force} \times \textit{Distance}}{\textit{Time}} = \textit{Power}$$

or

$$\frac{f \times d}{t} = P$$

How high can you jump? How long does it take you to jump as high as you can and come back down? It takes just as long to come back down as it does to go up. Use the mathematical sentence above to calculate your power output. Your weight is the force, the height you jump is the distance, and half the time needed for the round trip is the time. How much power do you put out when

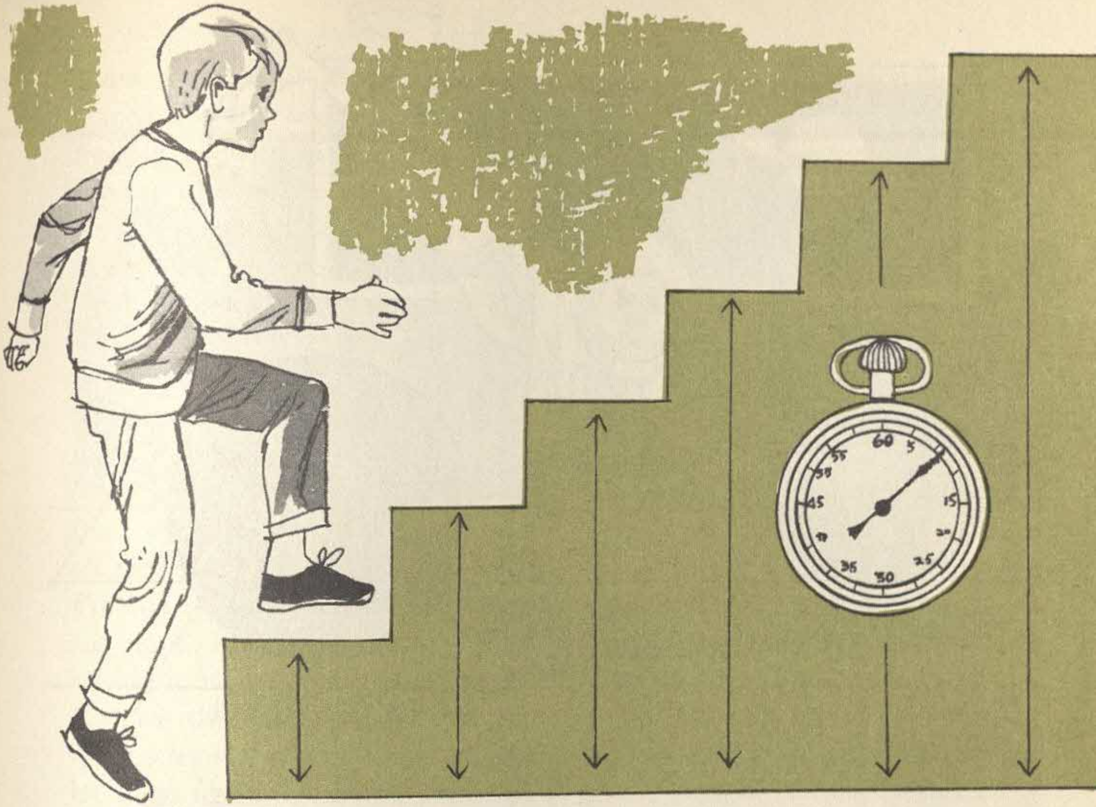
you jump as high as you can? Who in your class can put out the most power? A champion high jumper can leap over 7 feet. If a champion high jumper weighs 150 pounds and takes $\frac{2}{3}$ of a second to jump 7 feet into the air, how much power does he put out?

Power can be measured in foot-pounds per second, or foot-tons per hour, if you like. It can even be measured in crayon-inches per second. There are several special ways to measure power, too. Electrical power is measured in watts. Mechanical power can be measured in horsepower. One horsepower is 550 foot-pounds per second. The champion high jumper puts out about 3 horsepower when he jumps. Can you show how this calculation is made? How many horsepower do you put out when you jump as high as you can?

MEASURE

If you are in a school that has two or more floors, the next activity gives you an opportunity to calculate how powerful you are as you run up the stairs. If you are in a school without stairs, perhaps you can arrange to do this activity at home or some other place. The purpose of this activity is to see how much work you can do and how much power you can put out for a short time. Have someone else measure how long it takes you to run up the stairs. The easiest way to measure the height of

The power of this high jumper can be calculated.



the stairs is to measure the height of one step, and then multiply by the number of steps. Afterwards calculate how much work you did. The amount of work you did is equal to your weight multipled by the height of the steps. Then figure how much power you put out in foot-pounds per second. Now, if you like, you can calculate how many horsepower you put out.

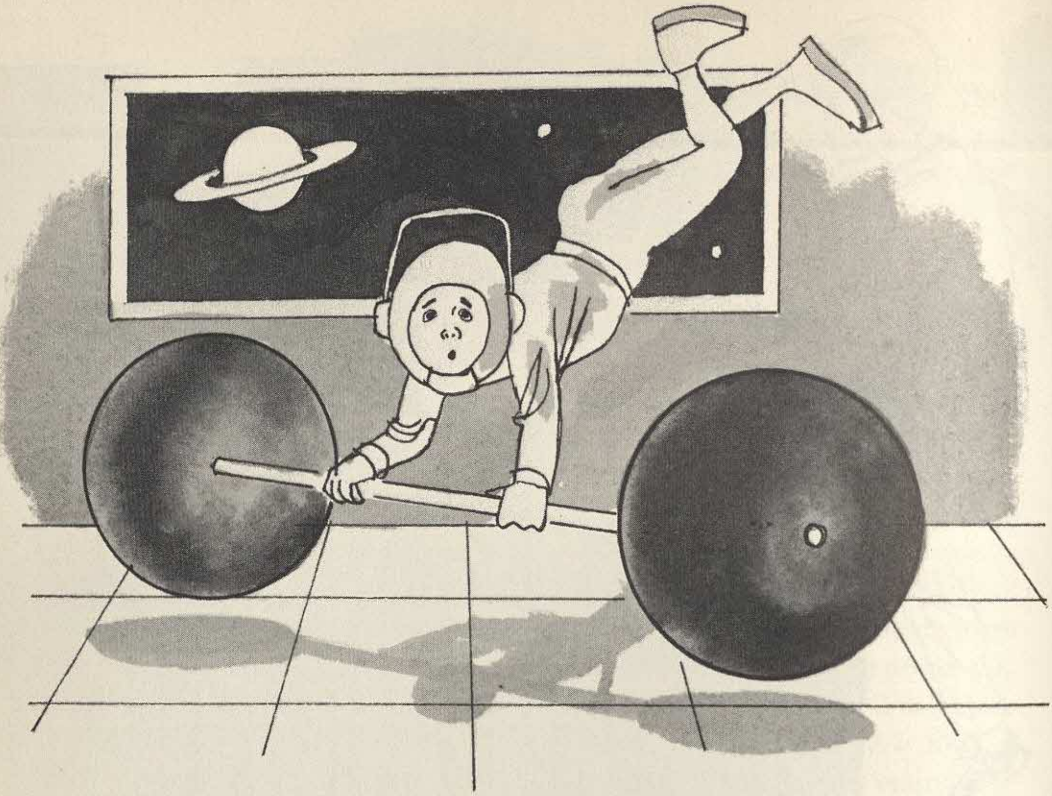
You can also calculate the amount of power you can put out pulling an object horizontally. One way to do this is to pull someone in a wagon for 100 feet, while somebody else times you. You can use a large spring scale to measure the amount of force you exert.

Momentum and Power

Before you began to study work and power, you read that momentum is the same as mass times velocity. If mass is measured in pounds, and velocity in feet per second, their product, momentum, must be measured in foot-pounds per second. These are the same units of measurement as the units of power. This means that momentum may be the same as power, and an object that is moving should be able to do work.

MEASURE

Obtain a large ball such as a volley or soccer ball. You will also need a cardboard box. Provide for enough room so that nothing will be



broken when you throw the ball at the box. Mark the position of the box. Now throw the ball at the box. How far did the box move? How much work would you have to do to move the box the same distance? How much work did the ball do? Did all of the momentum of the ball go to the box? How do you know? How can you show that the ball has more momentum when you throw it faster?

Weight and Mass

There are conditions under which any object, including yourself, can become weightless, but an object cannot become "massless." Matter always has mass. It only has weight when attracted by gravity.

If you were in a space ship in free fall, things in the space ship would be weightless, but they would still have the property of inertia. Do you think you would be able to move a weightless bar bell that weighs 5,000 pounds on earth? What would happen if you gave the bar bell a sudden push? What would happen if you continued to exert a force on the bar bell?

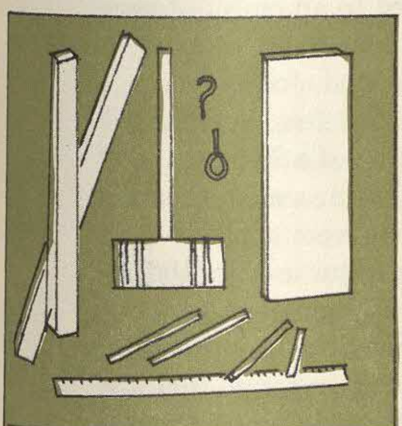
INVESTIGATE

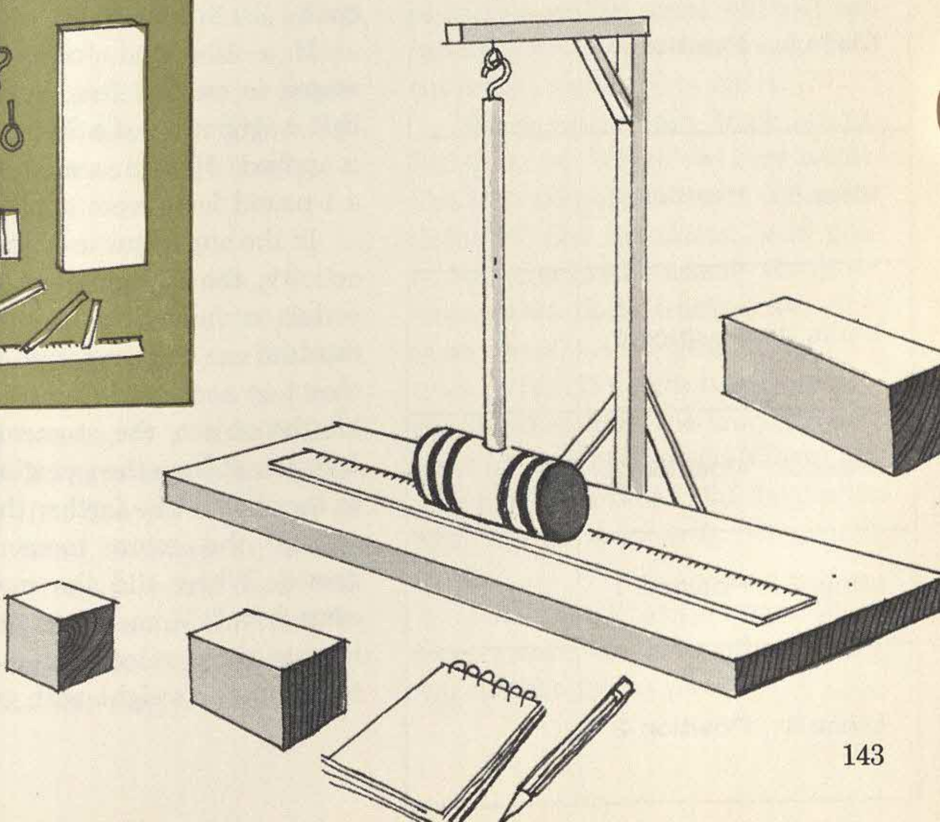
Make an apparatus like the one shown in the picture. The purpose of this equipment is to supply a force to various objects so you can see how they move when they are hit. Is it possible for you to exert the same amount of force several

times in a row? First, build the stand. You can use pine boards, or five-ply plywood. The hole through the top of the swinging arm should be large enough so that the arm swings with no noticeable friction. The bottom of the swinging arm should be built so that it just misses hitting the base of the stand. You will also need objects for the swinging weight to hit.

Saw a piece of wood 1 inch long from a length of 2″ × 2″. Also saw off pieces 2, 3, 4, and 5 inches long. Put the 1-inch object on the base of the stand. Pull the weight back and release it. How far did the object go? Replace the 1-inch block. Pull the weight back the same distance and let it go again. Does the object go the same distance? Mark the point at which the falling weight makes the object go about 2 inches. Try it a few times to make sure that the object goes the same distance each time.

Now find how far you have to pull the weight back in order to make the object go twice the distance. Notice that this is not twice as far back. Can you explain why? Find the position to which you have to pull the weight in order to make the object go three times as far. Finally, find the position from which the swinging weight will make the object go four times as far as it did originally. The marks on your apparatus should be somewhat similar to the ones illustrated below. Does





the side of the object the weight hits make any difference in the distance it goes?

Put your hand in place of the object. Now let the weight hit your hand so that you can feel about how hard the weight hits. If you have a small platform spring scale, you can put it in the object's position and see how hard the weight hits.

By sawing pieces from the same piece of wood, 1, 2, 3, 4, and 5 inches long, you have made objects with masses that are two, three, four, and five times as much as the mass of the original object. Make a data table like the one below.

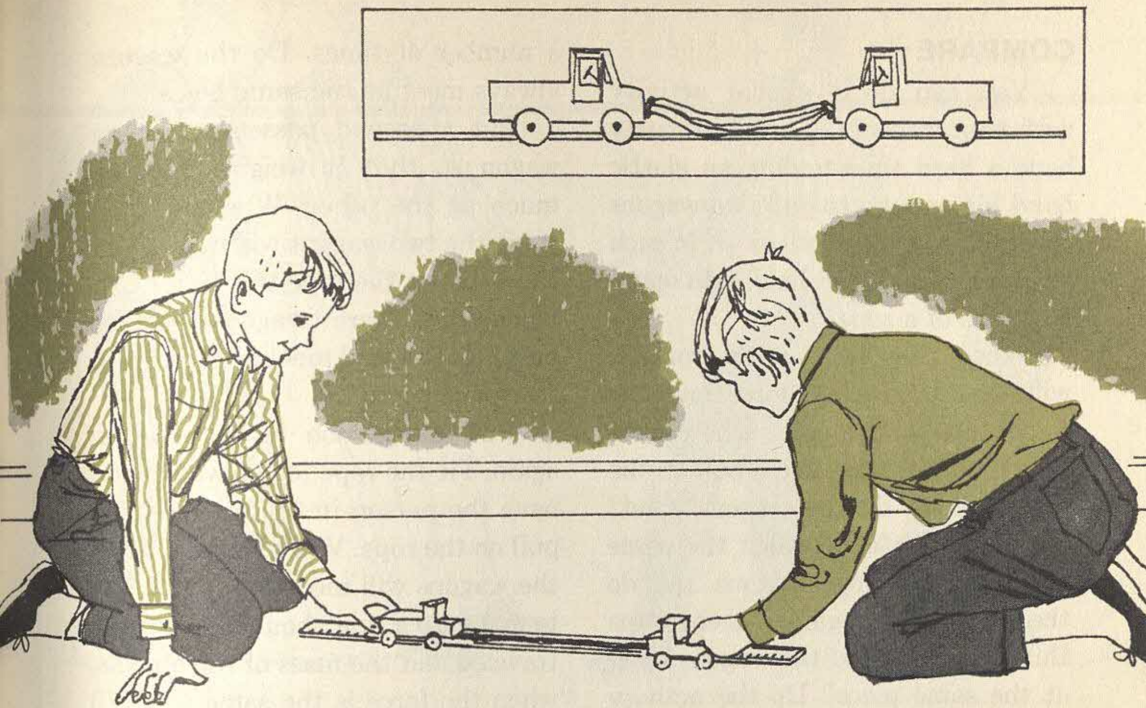
Mass	Distance
Mass 1 Position 1	
Mass 1 Position 2	
Mass 2 Position 1	
Mass 2 Position 2	
Mass 3 Position 1	
Mass 3 Position 2	

Now fill in the blanks on your table with the distances traveled. Put the object with mass two in place and hit it with the swinging weight from position one. Then hit mass two with the falling weight from position two, position three, and position four. Next do the same with the object with mass three. Continue this procedure with the objects having masses four and five. When you have finished filling in this table, you will have enough information to predict what will happen when any force is applied to any object.

Will doubling the force, double the distance an object goes? How far will an object with twice the mass go, when the same force is applied as was applied to an object of mass one?

If a 10-pound force causes a wagon to move 6 feet, how far will that wagon move if a 20-pound force is applied? How far would it move if a 1-pound force were applied? □□

In the apparatus used for the last activity, the swinging weight has a certain amount of momentum. Momentum can be transferred from one object to another. When the weight hit the object, the momentum was transferred from the swinging weight to the object. The farther the weight swung, the more momentum it gained. Where did the momentum come from? Momentum, remember, is mass times velocity. If you made the swinging weight with twice the



mass, it should have twice the momentum. Try it.

Increase the weight of the swinging pendulum until it makes an object go twice as far as it did before. Does the swinging weight weigh twice as much as it did before?

ACTIVITY

Obtain two toy trucks, friction carts, or model railroad trucks, a yardstick, some weights, and an elastic band about 6 to 10 inches long. The toy trucks, if you are using them, should have wheels far enough apart so that the yardstick can go between them, as shown in the picture. The trucks should face each other. Tie the elastic band to the front of the trucks. Make sure that the trucks roll freely. You cannot eliminate friction, but if you have the same amount on both sides, the effect of friction will be equal and will not interfere with the experiment. Pull the trucks about 2 feet apart.

Notice where each truck starts. Let them go! Where did they meet? Did both trucks go exactly the same distance? Did the elastic band pull on both trucks with exactly the same force? Did both trucks have the same mass? Add weights to one truck so that it weighs twice as much as the other. Pull the trucks 2 feet apart again. Let them go. Where did they meet this time? Did the elastic band exert the same force on both trucks?

If one truck has a mass three times greater than the other, where will the two trucks meet?

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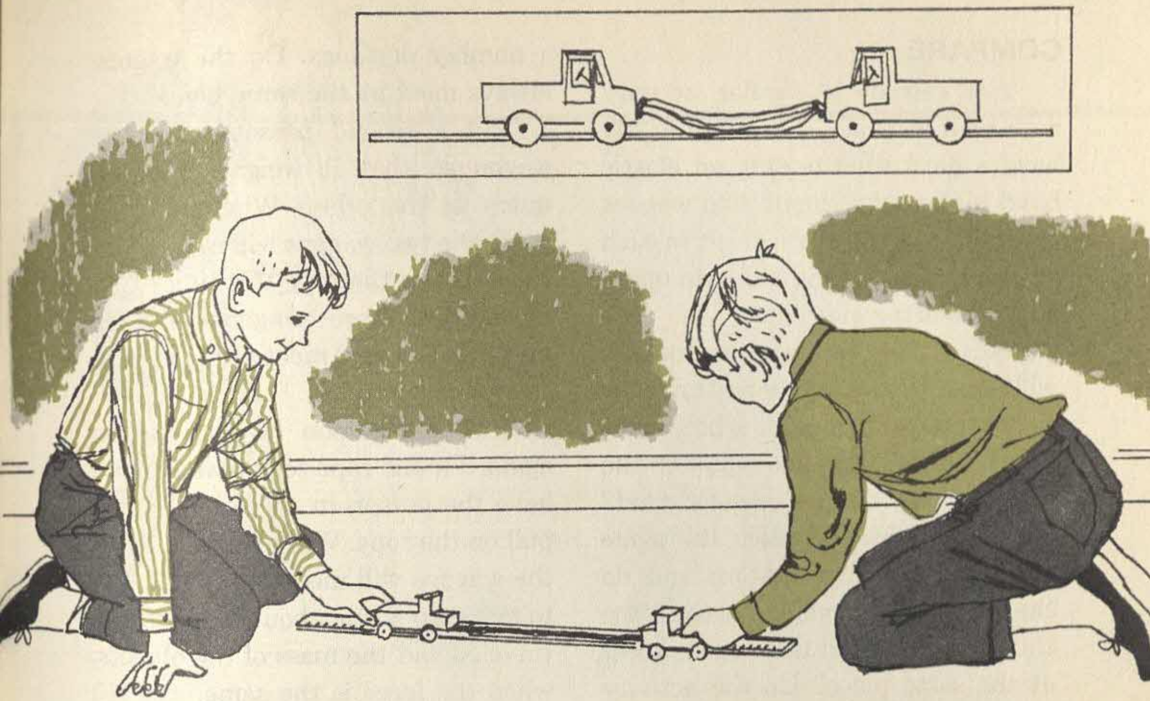

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If one truck has a mass three times greater than the other, where will the two trucks meet?

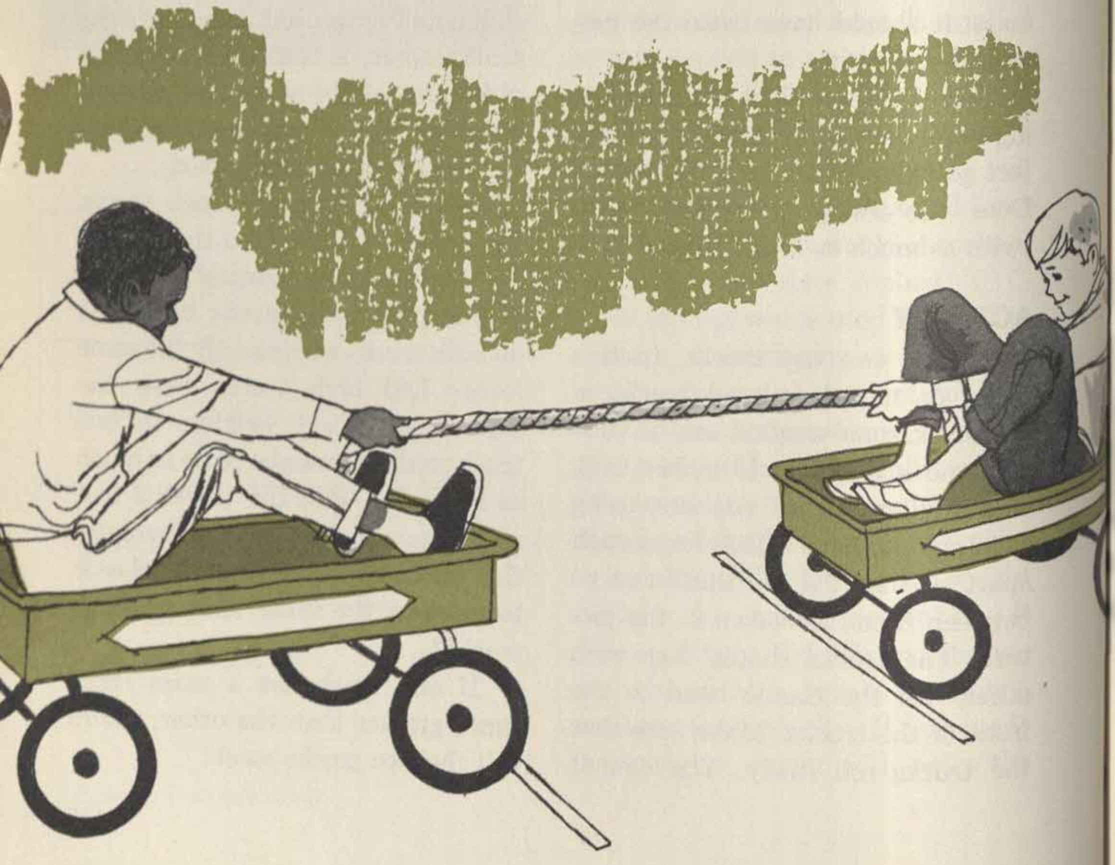
COMPARE

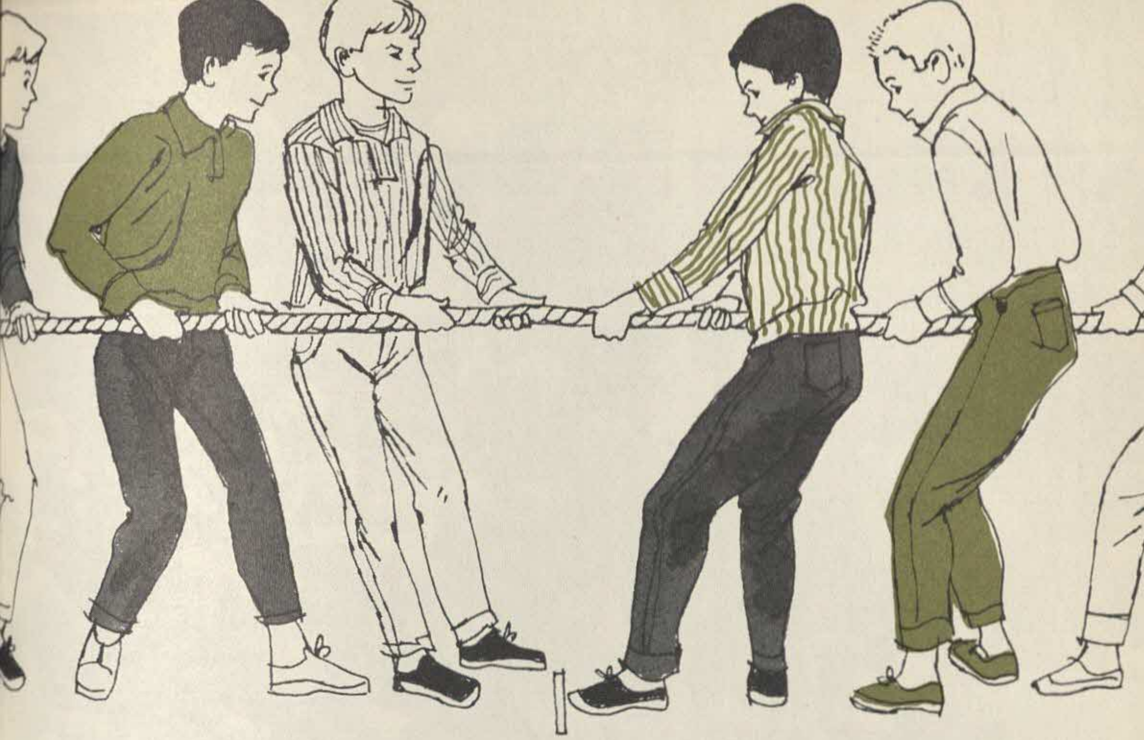
You can do a similar activity with your wagons. You will probably have a hard time finding an elastic band big enough to pull two wagons together, so a student can sit in each wagon and both can hold onto opposite ends of a rope.

When they pull on the rope, it will exert the same force on each wagon. Mark the point where each wagon starts. Have them pull on the rope. Where do the wagons meet? Did both students weigh the same amount? Exchange wagons and do the activity over again. Did the same thing happen? Did the wagons meet at the same place? Do the activity a number of times. Do the wagons always meet at the same place?

Put a second passenger in one wagon so that it weighs twice as much as the other. Where do you think the two wagons will meet when they pull on the rope this time? Can you predict where a wagon with three passengers would meet a wagon with two passengers?

Put one person in each wagon again. Tie the rope to one wagon and have the person in the other wagon pull on the rope. Where do you think the wagons will meet this time? Try to make up a rule about the distance traveled and the mass of the objects, when the force is the same. □□





Have you ever watched children having a tug-of-war? Several children on two teams pull on a rope as hard as they can. They each try to pull the other team over a line that is scratched in the ground. Is more force applied to the rope when two teams are pulling against each other or when the rope is tied around a tree with one team pulling on it? Can you think of some way to experimentally find the answer to this question?

MEASURE

Get the spring scale. Tie a piece of thread to the leg of a desk or table. Tie a loop in the other end of the thread. Hook the loop onto the spring scale. Pull on the spring scale until the thread breaks. Does it take much force to break the thread? Do the experiment again with another piece of the same thread. Does it always take about the same amount of force to break the thread?

Now, instead of tying the thread to a table or desk, have a classmate pull on the thread while you pull on the spring scale. How much force is required to break the thread?

How would you explain what happened? Can you predict what would happen, if you tied a piece of the same thread between two spring scales and pulled until the thread broke? Would each spring scale show the entire force? Or would each scale read half of the entire force? Do the experiment and see if you are correct. What evidence do you have that every force has an equal and opposite force? Which of Newton's laws best describes this activity?

You have probably watched football games on television or on the athletic field. Have you ever seen two players trying to push one another out of the way? Is there any real difference between pushing against another player and pushing against the wall? Perhaps some of the boys will try this activity. Two boys about the same size should push against one another. Each boy should push straight, and not try to slip by sideways. Now have another boy push against the wall. Do you think the wall pushed back as hard as the boy? Did this activity provide you with any evidence about The Third Law?

Acceleration

When objects move they often change their velocity. The name given to a change in velocity is *acceleration* (ak-*sell*-ur-AY-shun). Objects can speed up or slow down. When an object is gaining speed, we call the acceleration *positive*. When an object is losing speed or decelerating, we call the acceleration *negative*.

Very early in this unit you made a ball of paper and threw it up into the air. Do this activity again. When was the acceleration positive? When was the acceleration negative? What causes the positive acceleration? How does gravity affect the ball?

OBSERVE

Obtain a large ball. Roll the ball across the floor. When was the ball positively accelerated? When was the ball negatively accelerated? What force accelerated the ball? What force caused the negative acceleration?

Let a marble roll down an inclined board. When does the marble accelerate positively? When is the marble negatively accelerated? What forces positively accelerated the marble? What force caused the negative acceleration?

You have learned that acceleration is the change in velocity of an object. To measure the acceleration of an object you need to know how fast the object was moving both at the start and at the finish of its motion. You also must know how much time was required to accelerate the object.

The terms that are used most often to describe these changes in velocity are the *initial velocity*, which is the velocity of an object at the beginning of the acceleration, and the *final velocity*, which is the velocity that an object has at the end of the acceleration.

Imagine a car going 55 miles per hour on a straight road. The driver steps on the gas and the car accelerates to 60 miles per hour in 10 seconds. The initial velocity in this case is 55 miles per hour. The final velocity is 60 miles per hour. This means that the car had a change in velocity

Acceleration is very high in the X-15, as it increases speed rapidly in a short amount of time.

of 5 miles per hour. It took 10 seconds for this change. Since acceleration means a change in velocity divided by the time required for the change, you can calculate the car's acceleration. How would you calculate the acceleration of the car? How much change in velocity took place each second? What was the acceleraation of the car?

PROBLEM

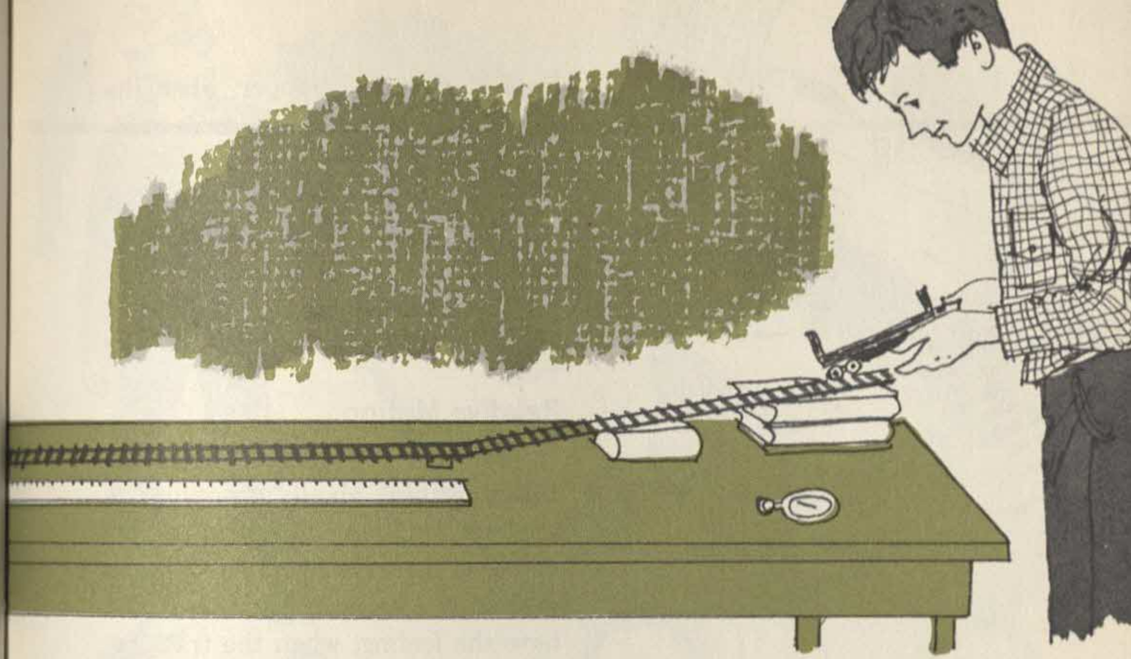
A marble rolls down an inclined board that is 2 yards long. At the end of 3 seconds the marble rolls off the end of the board with a velocity of 24 inches per second. Its initial velocity was 0 inches per second because it was standing still. Its final velocity was 24 inches per second. What was its acceleration?

Notice that acceleration is a change in velocity in a unit of time, so acceleration can be measured as a distance per second divided by the number of seconds.

PROBLEM

The initial velocity of an automobile is 44 feet per second. The final velocity is 66 feet per second. It takes 20 seconds for the automobile to change its velocity. What is the acceleration? Is the car speeding up or slowing down? How do you know?

A sky diver accelerates during his fall toward earth.



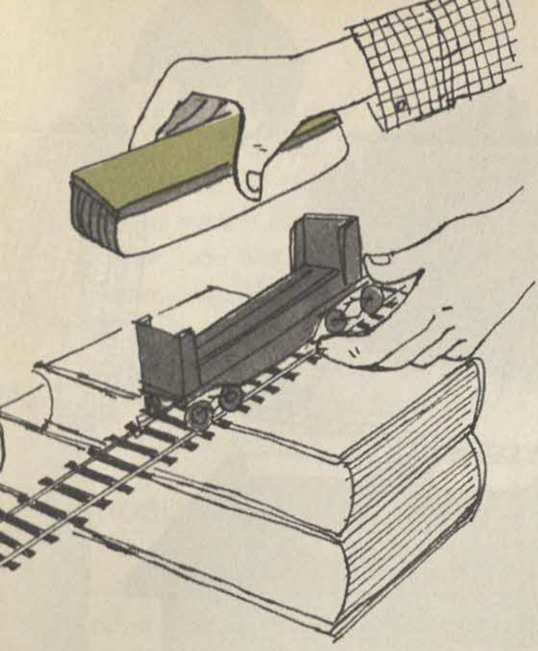
ACTIVITY

In this activity you will gather enough information to calculate the acceleration of a moving object. Arrange some model railroad tracks, as shown in the picture. Use a flat car for the moving object. Notice that the inclined track must be supported in the middle, otherwise the steepness of the hill will vary from place to place.

You should have a hill that is 3 or 4 inches high at the top, and about ½ inch above the surface of the table or floor at the bottom. The coasting track at the end should have just enough of a grade or slope so that the car will neither accelerate nor decelerate. This little slope is to overcome friction. You can test this slope by placing the car on it. If the car starts to roll, this means that the slope is too steep. If you give the car a little push and it slows and stops, the slope is not steep enough. Make the correction in the slope.

Place a yardstick alongside the coasting track so you can measure distances. You will also need some way to time the acceleration and the coast. You might use a stop watch or a clock with a second hand. You might also use a metronome from the music room. If you use a metronome, adjust it so that it makes one tick per second.

Place the railroad car at some point near the top of the hill. Let it go. How long does it accelerate? Move the car back to the starting position again. Let it coast down the hill again. Does it take the same time to coast from the same starting position to the bottom of the hill? Write down the length of time the car accelerates. Now you know that



an object starting at rest has an initial velocity of zero. Write it down. What was the time of acceleration? You already have that written down. So, all you are missing is the final velocity. To find the final velocity measure the distance the car moves in one second along the coasting track. Release the car from the starting position and start counting at the exact instant the car is at the *bottom* of the hill. How far does the car go in one second? This is the final velocity. Now calculate the acceleration of the moving object on the hill. Remember, acceleration is equal to the change in velocity per unit of time.

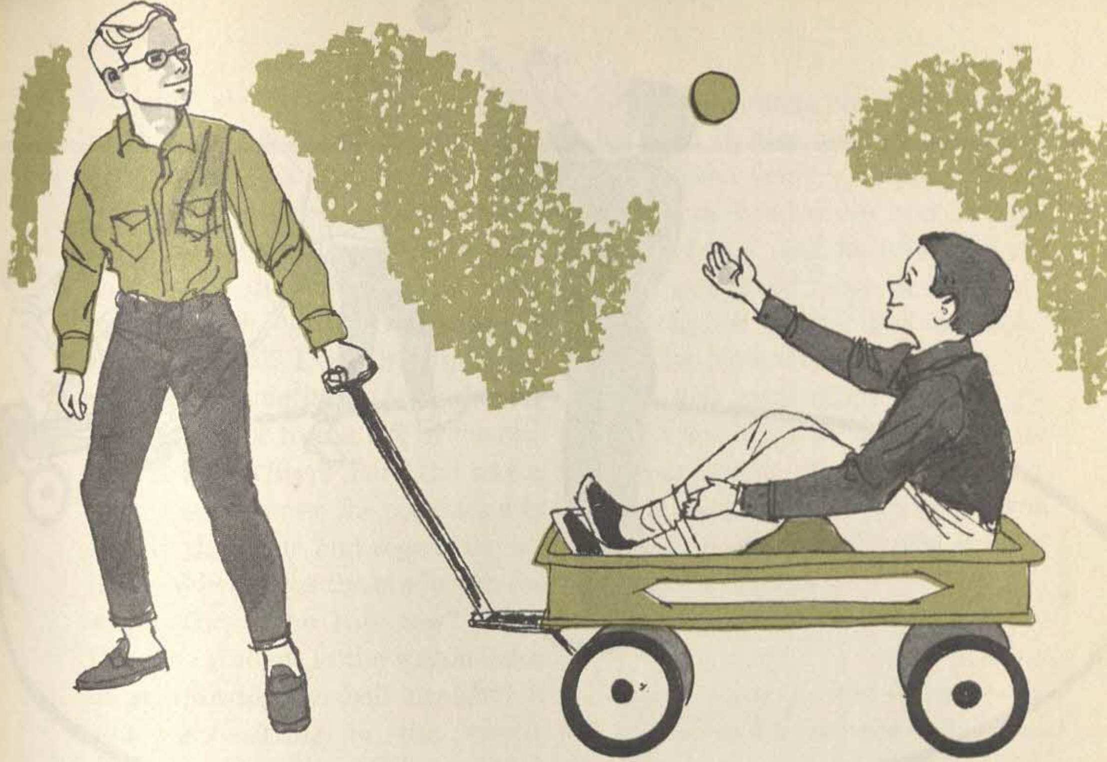
MEASURE

Change the slope or steepness of the hill and measure the acceleration again. When the hill is steeper, how does the acceleration change? Try to predict what will happen when the slope of the hill is made more gradual. Were you correct?

Put a heavy weight in the flat car, and measure the acceleration. Is the acceleration of the loaded flat car the same as the acceleration of an empty flat car on the same slope?

Relative Motion

One of the most interesting things to think about, when you are studying motion and how things move, is *what* is moving. Did you ever sit in a train in the station and have the feeling, when the train began to move, that it was the station that was moving? Have you ever been in an automobile with trucks



and cars passing on either side and wondered whether you or the other cars were really moving? Have you ever been on a merry-go-round and thought that you might be standing still and the whole world was going around? Have you ever noticed while riding in a moving car, that you could be sitting very still? Have you ever walked down the aisle of a moving bus, and noticed that you were moving while the rest of the passengers were sitting still?

All of these experiences have to do with the idea of *relative motion.* So far in this unit you have been looking at motion and moving objects from the outside. You were standing still and the object was moving. Now it is time to take a closer look at the motion of objects in relation to each other. We shall see motion from a new point of view. Start by bringing a wagon to school again.

EXPLORE

This activity should be done in a large room or outside on the playground. Have a student in the wagon throw a ball up in the air and catch it when it comes down. The ball should go 8 to 10 feet in the air. Do you have any trouble catching the ball when it comes down? If you throw the ball straight up, does it come straight down?

Now have another student pull the wagon in a straight path. Do not change the velocity of the wagon too quickly. Continue to throw the ball up in the air and catch it when it

comes down. Do you have any trouble catching the ball? When you are in the wagon, does the ball go straight up and come straight down? Watch while someone else sits in the wagon and does this activity. When the wagon is moving, does the ball go straight up and come straight back down? What path does the ball appear to follow when you look at it from the outside of the wagon? What path does the ball appear to follow when you look at it from the inside of the wagon?

What path does the ball appear to follow in relation to the wagon? What path does the ball appear to follow relative to the ground? Is the description of the motion of the ball as seen from the wagon more correct than the description as seen from the ground? Why? On what does the correctness depend?

EXPLORE

Using chalk, draw a large circle on the floor or on the playground. Have one student stand in the center of the circle and another sit in a wagon parked on the circle. Try to select students who throw and catch well. The two students should now play catch with the ball. Does either student have any trouble catching the ball? Now have a third person pull the wagon around the circle. He should move at a steady pace. While the wagon is moving, the

students should continue to play catch. Does either student have a hard time catching the ball now? Why? Where does the student who is in the wagon have to throw the ball? Where does the student who is in the center of the circle have to throw the ball? Does the student in the wagon sometimes throw the ball to the right or to the left of the student in the center? Turn the wagon around so it moves the opposite way around the circle and repeat the activity. Where does the student in the wagon throw the ball now? Why? Does the student in the wagon think he is throwing the ball straight? If you were sitting in the wagon, throwing the ball, would you think the ball was moving in a straight line?

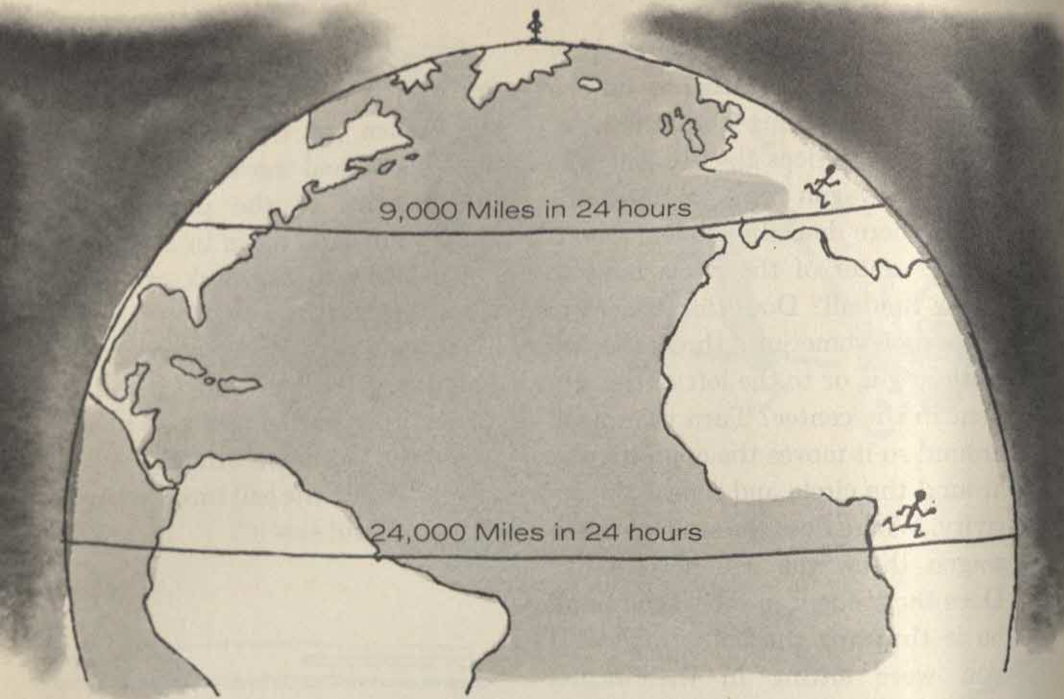
INVESTIGATE

For this activity you will need a phonograph, a crayon, and a sheet of heavy paper or cardboard. Cut a circle of cardboard the same size as the turntable of the phonograph. Make a hole in the center of the cardboard for the spindle to stick through.

With your crayon, draw a line from this hole to the edge of the circle of cardboard. Place the cardboard circle on the turntable, and turn on the phonograph. Can you draw another straight line from the edge of the circle to the center? What shape is your line? Do you know why?

When your paper is all marked up, turn it over and use the other side. When you try to draw a line, does your hand move in a straight line relative to the phonograph? Does your hand move in a straight line relative to the desk or table? Try to explain why. □□

If you were riding a merry-go-round and tried to throw a ball to a friend not on the merry-go-round, would the ball travel straight as you saw it? Would the ball travel straight as your friend saw it?



How fast are you moving at this moment? Does your answer include the turning earth? How far is it around the earth at the equator? How many times does the earth rotate on its axis each day? How many miles does a person travel in one hour, if he is standing still in a country on the equator? How fast is a man moving who is standing still on the equator?

How fast is a man at the North or South Pole moving? If a man stood at the North Pole with one foot on either side, how long would it take him to make one complete turn? Find the location of your school on a map of the world or on a globe. How fast are you moving? Can you feel your motion? Are you accelerating? Now try to find out how fast you are moving around the sun. Can you feel this motion?

Does the sun move across the sky? Does the sun move around the earth? Does the earth move around the sun? On what do these answers really depend?

Motion is relative. In our everyday thinking we usually agree that the ground is fixed in one position and that motion takes place relative to the ground. But activities such as the ones you did with the ball and the moving wagon, show that this way of thinking can lead to difficulties. For instance, if you are riding in an automobile at a high speed of 65 miles per hour and the car should suddenly stop moving, relative to the surface of the earth, you would go flying through the wind-

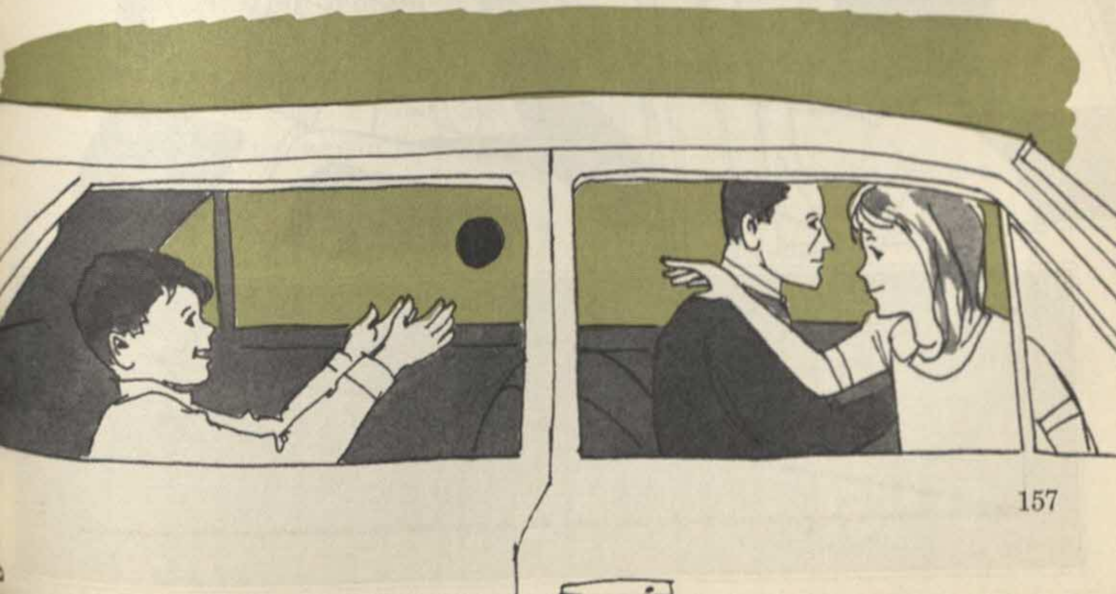
The motion of this plane is measured relative to the ground.

shield. Or, if your car is following another car at 65 miles per hour, and the car ahead should suddenly decrease its speed, relative to yours, you would be in great danger.

Whenever you measure a speed, a velocity, or an acceleration, you measure it relative to the speed, velocity, or acceleration of something else.

If you are in the back seat of an automobile that has a velocity of 22 feet per second, and you throw a ball with a velocity of 10 feet per second to someone in the front seat, how fast is the ball moving relative to the ground? How fast is the ball moving relative to the car?

If the person in the front seat throws the ball back to you with a



velocity of 12 feet per second, how fast is the ball moving relative to the ground? How fast is the ball moving relative to the car?

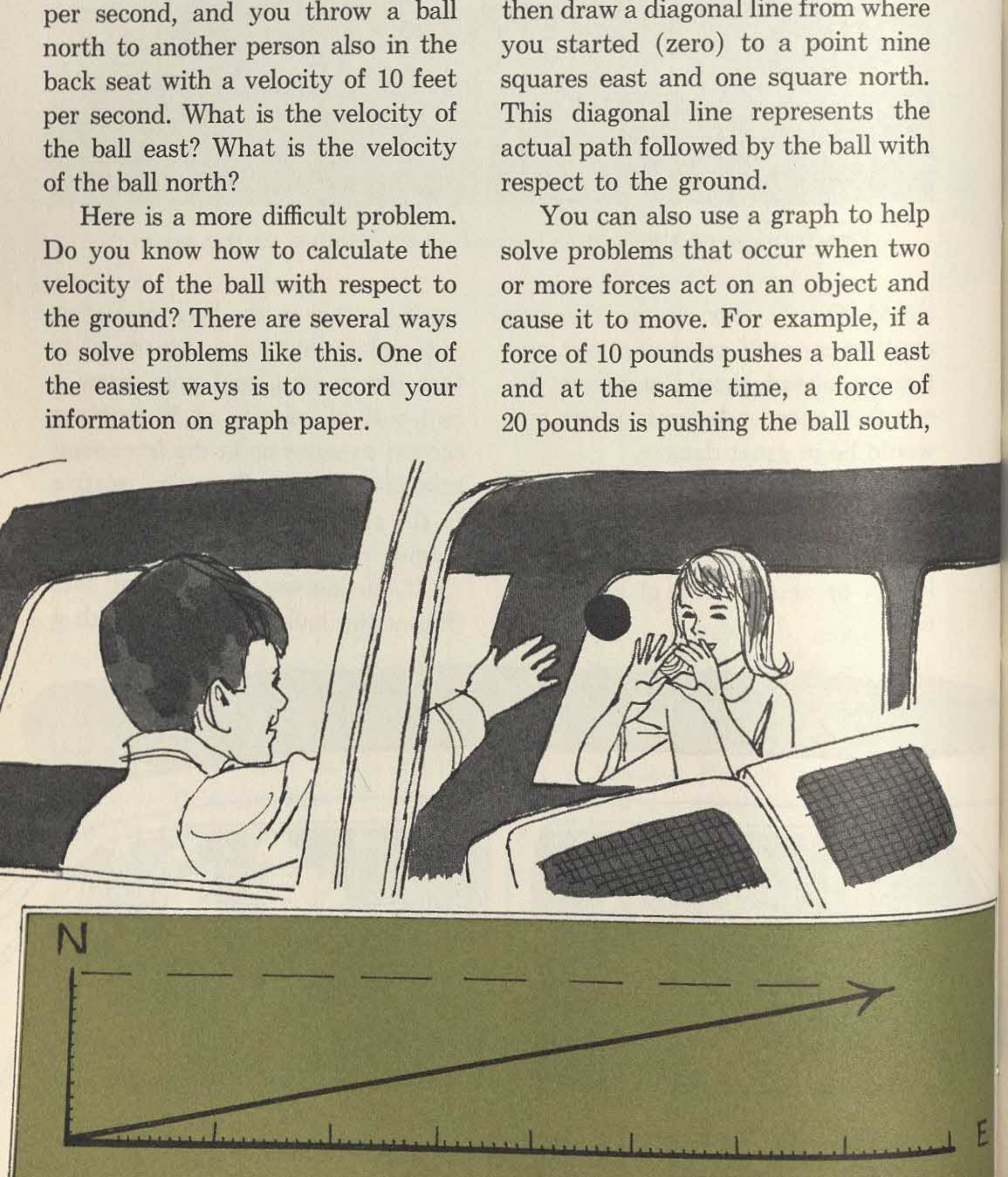
IMAGINE

Pretend that you are in the back seat of a car going east at 90 feet per second, and you throw a ball north to another person also in the back seat with a velocity of 10 feet per second. What is the velocity of the ball east? What is the velocity of the ball north?

Here is a more difficult problem. Do you know how to calculate the velocity of the ball with respect to the ground? There are several ways to solve problems like this. One of the easiest ways is to record your information on graph paper.

To solve the problem you would mark off nine large squares to the east to represent the 90 feet per second velocity of the car, and mark off one large square to the north to represent the velocity of the ball. Each large square represents ten units of one foot per second. You then draw a diagonal line from where you started (zero) to a point nine squares east and one square north. This diagonal line represents the actual path followed by the ball with respect to the ground.

You can also use a graph to help solve problems that occur when two or more forces act on an object and cause it to move. For example, if a force of 10 pounds pushes a ball east and at the same time, a force of 20 pounds is pushing the ball south,



where would the ball go? You should draw a line that is ten units long east, and one twenty units long south. A diagonal line from the starting point to a point ten east and twenty south shows the path the ball would follow. Do this for yourself. Can you explain why this graphic method works?

Periodic Motion

When you studied light and sound, you first met the idea of motion that repeats itself. You probably discovered that a vibrating object can make a sound. You may have learned the words amplitude and frequency. You also encountered *periodic motion* earlier in this unit, when you saw a model railroad truck accelerate down a hill, decelerate as it coasted up the next hill, coasting back and forth until it came to rest. Here is another activity to help you understand periodic motion.

EXPERIMENT

Tie a string around a small weight, such as a metal nut, and then suspend the string from a stand or from the edge of your desk as shown. Pull the weight back and let it go. What happens? You have just made a simple pendulum. How long does it take for your pendulum to make one swing forward and back? In other words, what is the *period* of your pendulum? If you make the string longer, will the period of the pendulum become longer or shorter?

What do you have to do in order to make the period of the pendulum twice as long as before? What do you have to do to make the period of the pendulum one-half as long as it was? One way to answer these questions is to experiment with your pendulum.

Look for rules which seem to apply to different pendulums. How does the weight of the pendulum affect the motion of the pendulum?

Would you agree that the best way to discover the rules controlling pendulums is to change things and keep track of what happens when they change?

Make changes like the ones on this page. Try making the string on your pendulum one-half as long, one-quarter as long, twice as long, and four times as long. Fill in the blank spaces on your chart. Does this help you to answer the questions about pendulums?

What effect does the weight of the pendulum bob have on its period? Make the weight of the pendulum bob twice as much, three times as much, and four times as much, by using 2, 3, and 4 metal nuts. Fill in the blank places on your chart.

What can you say about the effect of the weight of a pendulum bob on the period of the pendulum? If two children sit in two swings with chains of the same length, will they have the same periods? Try this on the playground and see. □□

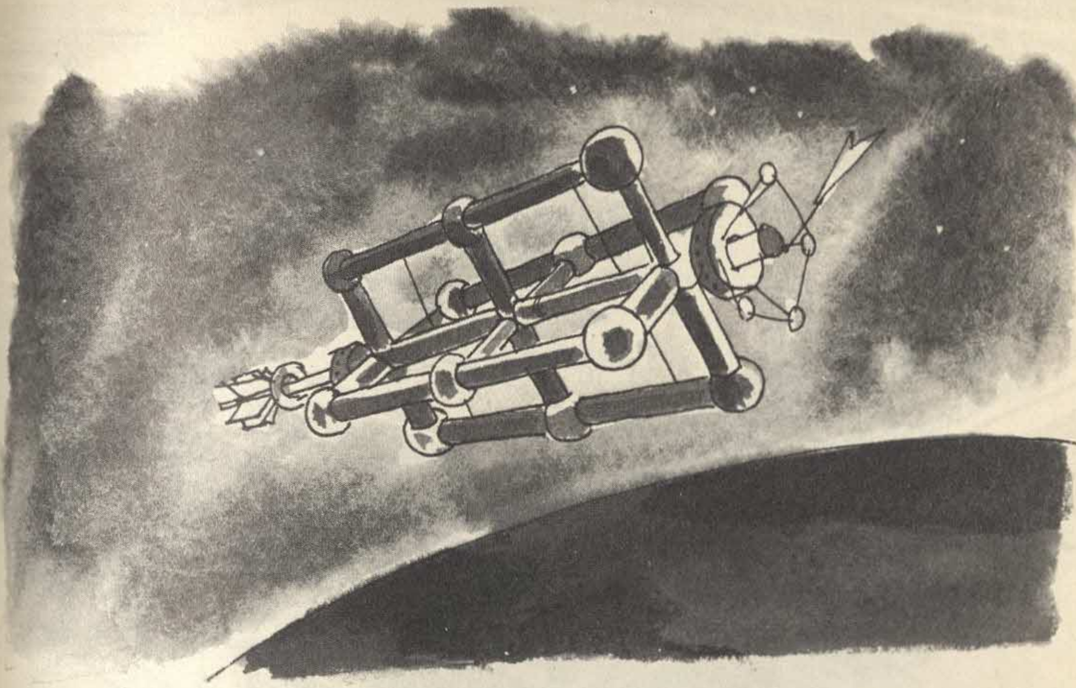
A grandfather clock has a pendulum whose period is just one second. The swing of the pendulum controls the clock. The mass of a pendulum has no effect on its period. However, the force due to gravity does have an effect. If gravity were four times as strong, the period of a pendulum would be only half as long. The gravity on the surface of the moon is only one-sixth as much as on the earth. If you took a grandfather clock to the moon, would it run faster or slower? How much faster or slower?

Rotary motion is similar to periodic motion in that the motion repeats itself. It is different in some ways as you shall see. Bring a bicycle into the classroom and turn it upside down. Spin the front wheel. Look carefully. When does the wheel accelerate? When is the wheel accelerated negatively? Why does the wheel come to a stop? What keeps it spinning? Does the wheel change its direction of rotation? Make a list of the differences between rotary motion and periodic motion. Make a list of the things that are the same in rotary motion and in periodic motion.

In periodic motion, the length of the period is a measure of how fast the motion is taking place. In *linear motion*, velocity is the measure of how fast the object is moving. In non-linear motion the speed is used to measure the amount of motion. How is rotary motion measured?

MEASURE

Tie a white or brightly colored cloth around the bicycle wheel. Give the wheel a spin. How many times does the wheel rotate in one minute? How many rotations does the wheel make in one second?



What is the measured distance around the outside of the tire? If the wheel were to roll along the ground, how far would it go in a second? How far would it go in a minute?

Find a smaller wheel. One on a wagon would be very good. Mark some point on the wheel so that you can determine the rate at which the wheel is rotating. Give the wheel a spin. How many turns does the wheel make in one second? How far is it around the outside of the wheel? How far would this wheel roll along the ground in a second? In a minute? Does your predicted result differ from your result when you try to roll the wheel? Why?

Turn back to the first page of this unit. Read the questions and statements on motion there. Can you describe the various examples of things in motion? Can you decide what kind of motion is involved in each instance? □□

You have answered a number of questions about motion in the process of working your way through this unit. There are many more questions about motion that you have yet to answer. For example, how does a wave move? How sharp a corner can a space ship turn? What keeps a satellite in orbit? What keeps the earth from falling into the sun?

The answers to these questions should come to you as you continue to explore the many kinds of motion in the universe. As you study more and learn as you study, you will find that each answer leads to new and more challenging questions.

THINK

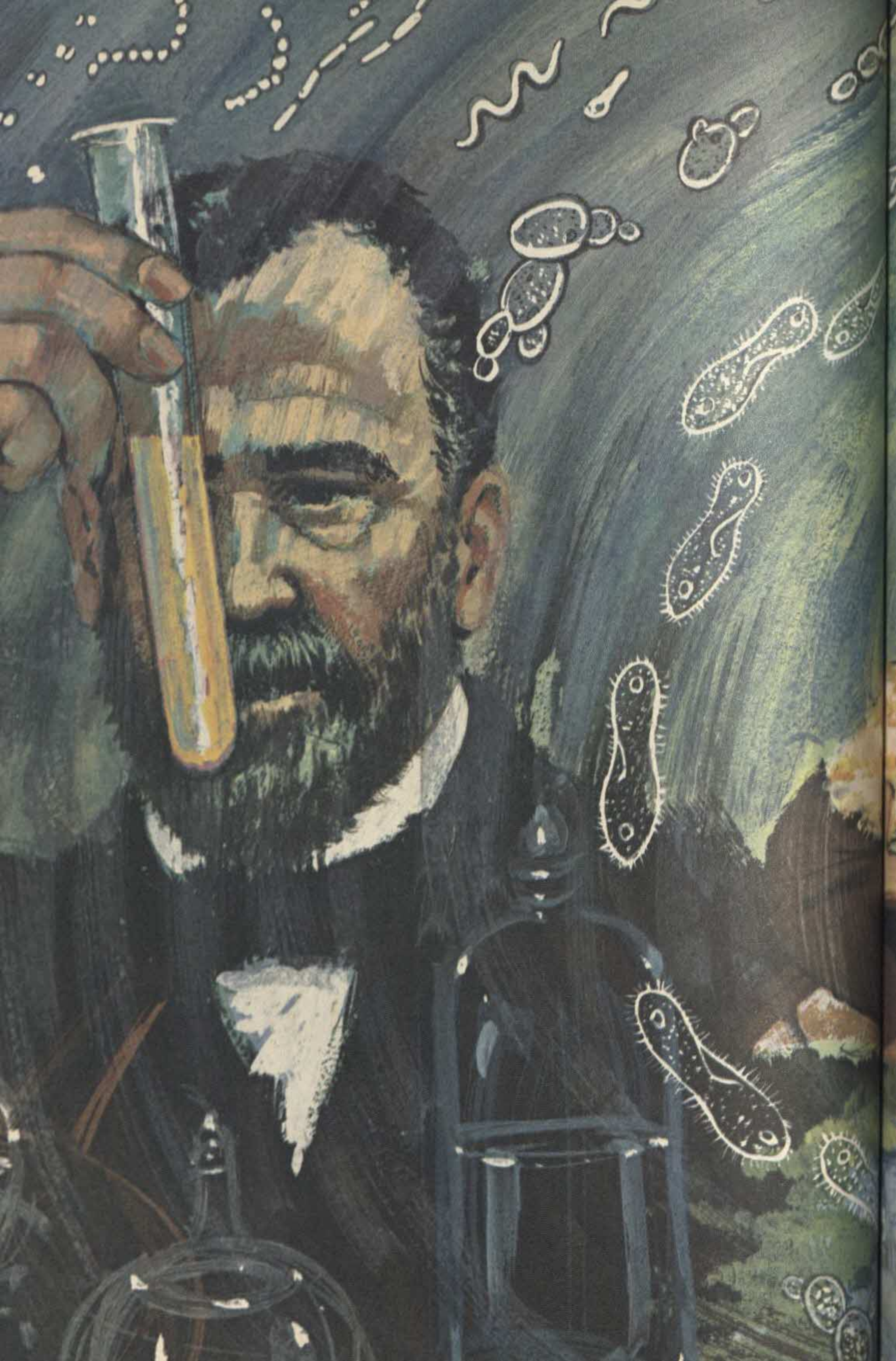
1. Would a moving object move forever if there were no friction? Explain your answer.
2. How would your life be different if there were no friction?
3. Two people riding in the same car were asked whether or not they were moving. One person said "yes", the other said "no". Both were correct. Why?
4. Why is it that a person quickly turning a corner feels a pull away from the center of the turn?
5. How would you show that mass (bulk) and inertia are closely related? What evidence do you have that they may be identical?

PROJECTS

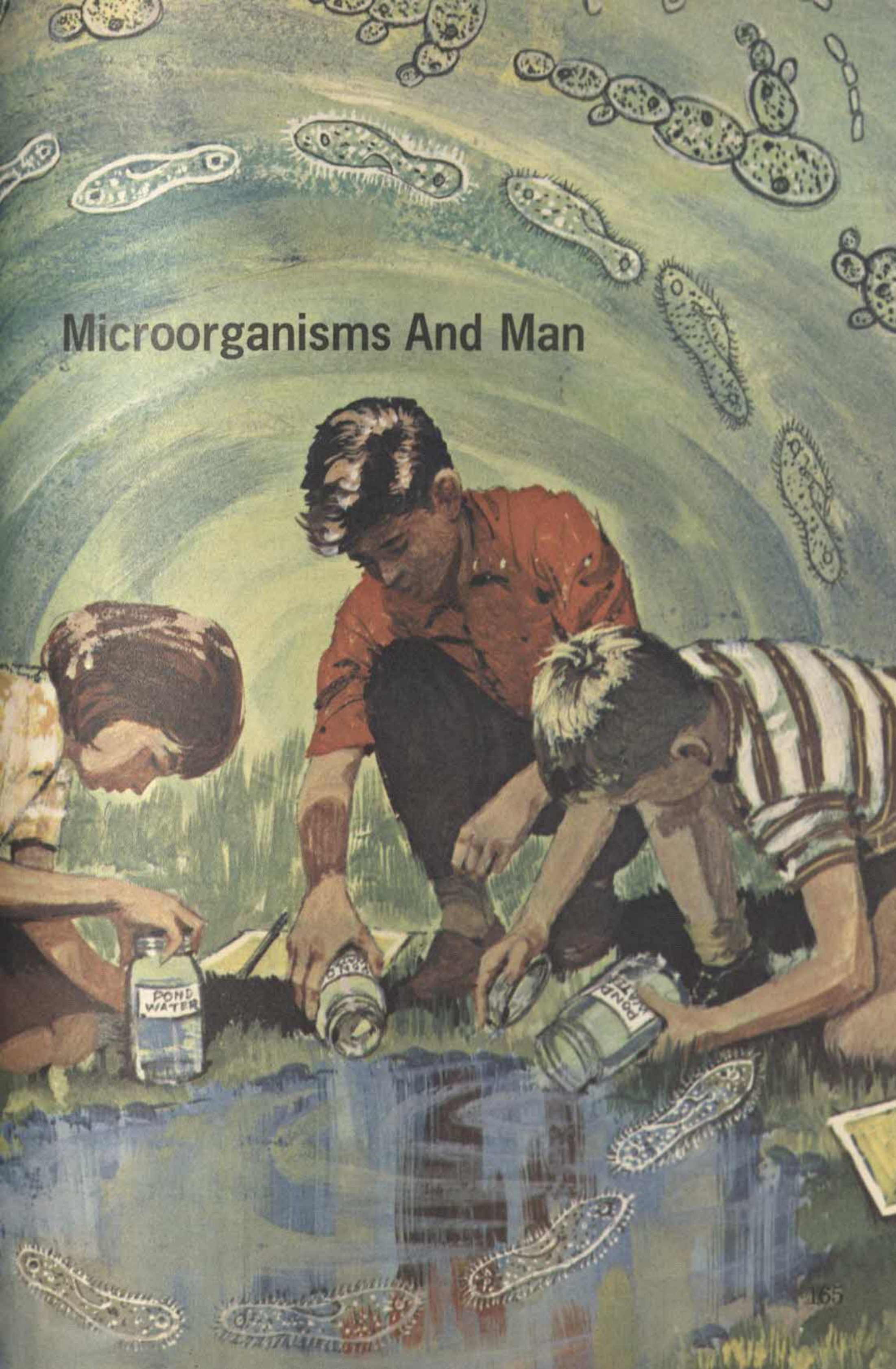
1. Design experiments that show the effect of gravity on objects of weight. Do all objects fall at the same rate in air? How can you show how objects would fall in a vacuum?
2. Design a series of experiments that demonstrate Newton's Third Law. Do not limit yourself to one illustration. Try to find evidence for Newton's Third Law in various moving objects. Show how the law applies to the starting and stopping of moving objects.

   Keep accurate records. Make data charts.

   If the need should arise, be prepared to report your findings to your class.



Microorganisms And Man



Tiny Living Things

Scientists have known for some time that there is a world of very tiny living things. Countless numbers of them are too small to be seen without a good microscope. Today it is known that many of these living things help people. Others cause a great deal of harm. Scientists have learned that some of them are plants and some are animals. Some they are still uncertain about. The study of these tiny plants and animals is called *microbiology*. The animals and plants from this strange microscopic world are called *microorganisms*.

As you study this unit, you will find out where they live, how they grow, what they are, and what they do. You will also find out through your own experiments how people learned about this tiny world which, until the invention of the microscope, no one had ever seen.

Seeing the Unseen

ACTIVITY

Have you ever observed living things in a drop of pond water?

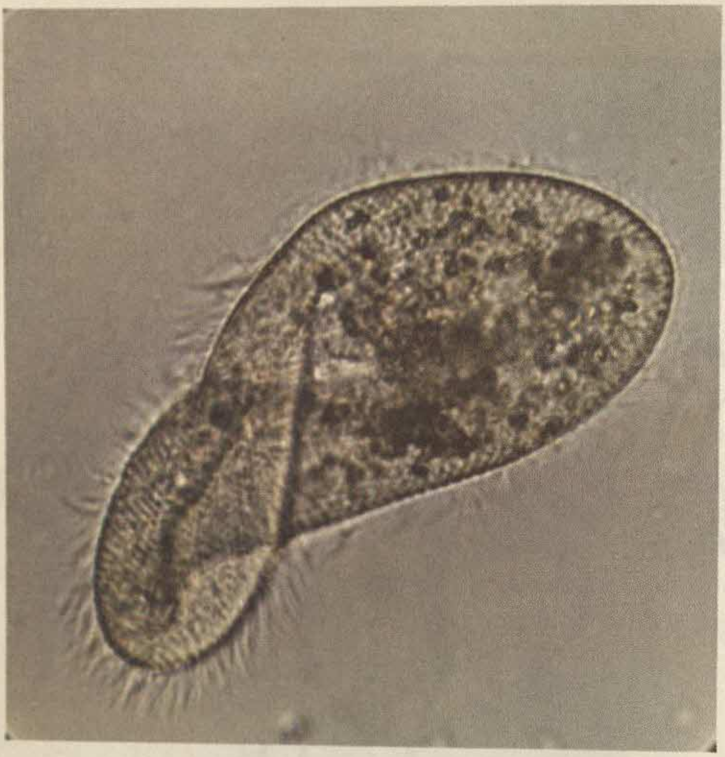
Collect pond water in a jar. Be sure to collect some of the mud from the bottom of the pond. Allow the water to settle for a few days.

Look as carefully as you can to see how many different objects you can observe in the jar. You may observe living and non-living objects. Can you describe them? What words would you use to describe the living things?

Obtain a magnifying glass. What appears to happen to the objects in the water when you look at them through the glass? When you use your magnifying glass, can you see some objects in the water that you could not see before?

Stir the water, but *do not* stir up the bottom. As the muddy water settles, take a medicine dropper full of water and place a few drops of it into a small watch glass or test tube.

First look at the water without the magnifying glass. Report what you see. Now look at the water with the glass. Can you see the living objects more clearly? Can you see some living things that you could not see before? Describe everything that you see. □□



How would you describe this animal?

Describe the animal in the picture. If you have a similar one in your pond water, tell how it moves. Scientists have given animals of this kind a clever name. They call each one that looks like this a *Paramecium* (*par*-uh-MEE-see-um), which is from a Greek word that means "oblong." Does this word describe the animal? Can you think of a better name? Animals similar to the paramecium live in nearly every fresh water pool and stream in the world.

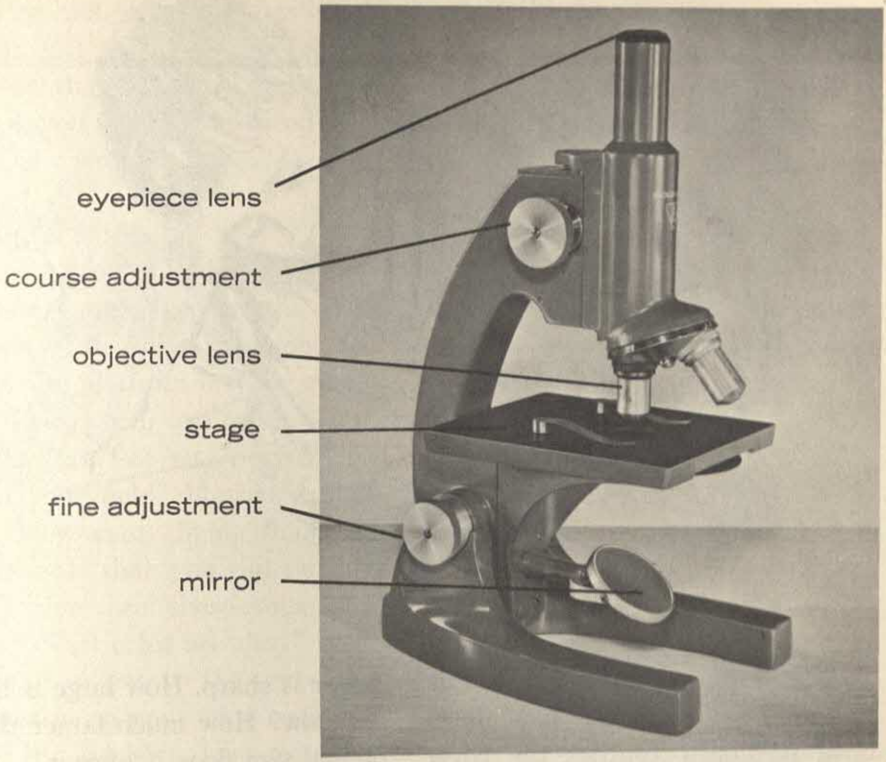
The Microscope

As you learn more about this strange world, it will be useful for you to know how to use a microscope and to make microscopic slides. What do you think the word *microscope* means? *Scope* comes from a Greek word meaning "to view." Do you know what *micro* means?

ACTIVITY

Look at your microscope and the one shown on the next page. Most microscopes are similar. They are all very delicate instruments.

Your microscope has at least two curved pieces of glass called *lenses* which work together. The lens nearest the object you want to see is called the *objective lens*. The lens nearest your eye is called the *eyepiece*.



There is a *platform*, sometimes called a *stage*, under the objective lens for placing objects. The *clips* on the platform hold the glass slides in place. Beneath the platform is a *mirror* which can be turned to reflect light through a hole in the stage. This light passes through the object you wish to see. Why is it necessary to reflect the light? Why do you think objects are placed on glass slides?

Place your eye near the eyepiece and turn the mirror toward a source of light. A good lamp or a bright window works well. Never turn the mirror directly toward the sun. Adjust the mirror until you see a clear round area of light without shadows. This circle of light is called a *field*.

Use a cloth to clean a glass slide and a cover slip. Place a small drop of tap water in the center of the slide. Now cut a small letter "e" from a newspaper and lay it right-side up in the drop of water. Slowly put the cover slip over the drop of water by setting one edge down first. One edge is placed first to prevent air bubbles from being caught between the cover slip and slide. Now place the mounted slide on the platform, clip it into place, and move it with your thumbs and forefingers until the letter "e" is in the center of the platform opening.

Turn the *coarse adjustment knob* to move the objective lens down until it almost touches the cover glass. Be careful! Watch from the side, in order to be sure your objective lens does not touch or break the slide.

Place your eye near the eyepiece and, as you look in, turn the coarse adjustment slowly toward you. This will raise the *body* of the tube and the lenses. Watch for the letter "e" to appear in the field. To get a clearer view, gently turn the smaller wheel back and forth. This wheel is called the *fine adjustment*. When in proper focus, the objective lens will be slightly above the slide. Why should the microscope always be focused by raising the body tube?

Move the adjustment up and down slowly until the focus of the letter is sharp. How large is the letter now? How much larger than its actual size does it appear?

Using your thumbs and forefingers, move the slide to your right. Which way does the letter appear to move as you look at it through the eyepiece? Move the slide to the left. What happens now? Move the slide away from you and toward you. What happens? Can you explain why this happens? Is everything you see through the eyepiece reversed?

Make another slide. Use another letter to be sure that you know how to do it. Did you get any air bubbles this time? What do air bubbles look like when viewed through the microscope? How can you avoid getting the bubbles?

The microscope is a tool for the scientist. It "improves his eyesight"

by letting him observe things which he could not normally see with his eyes. Now that you know how to use this tool, you are ready to study the microscopic world.

OBSERVE

Place a drop of your pond water on a slide. Carefully place the cover glass over the drop. Now put the slide on the platform of your microscope. Bring your microscope into focus. Do you see any microorganisms in your field? Move the slide slowly. How many living things do you see now that you did not see before? How are these organisms shaped? What color are they?

What happens to the organisms as the water on your slide begins to dry up? If you wish to keep using the same slide, just place a little more water along the edge of the cover glass. After looking at the water through the microscope, can you make a good guess about the number of organisms in a drop of water? How might you check your guess?

COMPARE

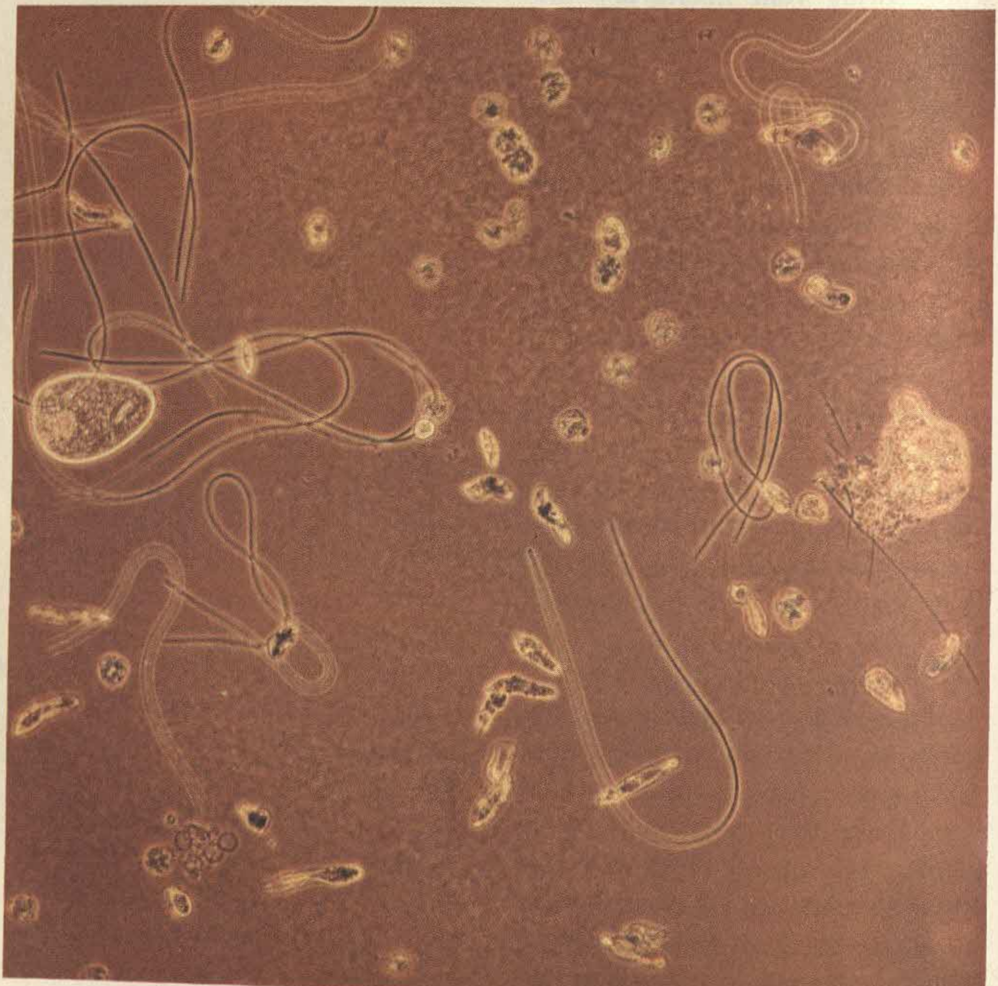
Transfer the water from the container in which you have your pond water stored, leaving the silt behind. Now shake the "clear" part of the pond water several times and pour equal amounts into 3 clean bottles. Store one bottle in a refrigerator at school. Leave one in your classroom. Keep one in a warm place. After twenty-four hours, take a drop from each bottle. Put each drop on a separate slide and study the samples under your microscope. Is there a difference between the one kept in the refrigerator and the one kept in a warm place? What effect does temperature have on the organisms? What does light do to the organisms? Can you make up an experiment to see what effect light has on microscopic animals?

RECORD

Obtain several samples of water from other places. You might use water from a stream, a puddle, and a faucet. Make a slide for each type of water. Label the slides so that you don't get them confused. Do you find any similarities or differences in the kinds and numbers of organisms in the various samples? Keep a record of what you observe. □□

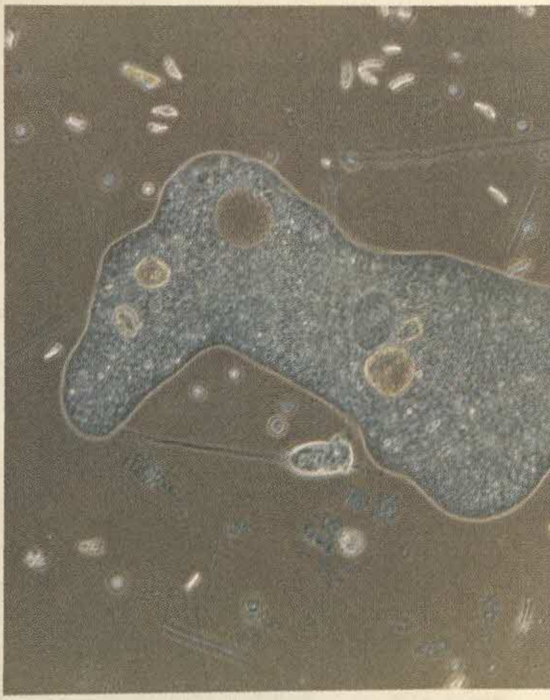
Below is a highly magnified photograph of a drop of pond water. Have you seen any of these organisms under the microscope? If there are some different ones, look more carefully at your live samples under the microscope. Draw what you see.

Now you will have a chance to observe and experiment with different types of microorganisms.



How do these microorganisms compare with the ones you have seen?

Stentor



Ameba

Protozoa

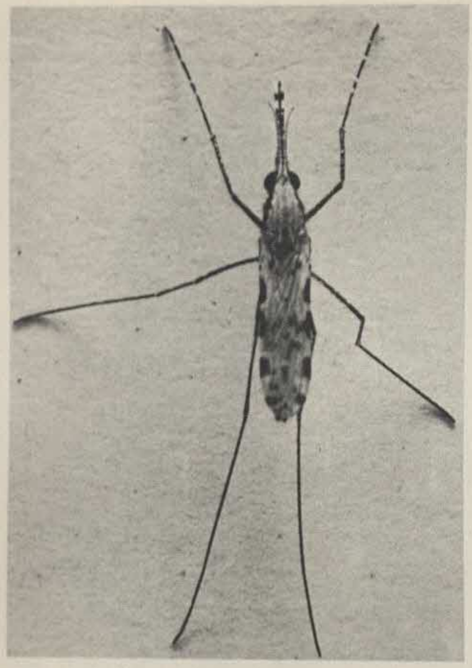
Pictured above are some of the larger organisms which are often found in pond water.

Describe these animals. How are they similar to or different from the paramecium? Did you see any organisms that resembled these in your pond water? Draw pictures of the tiny living things that you see.

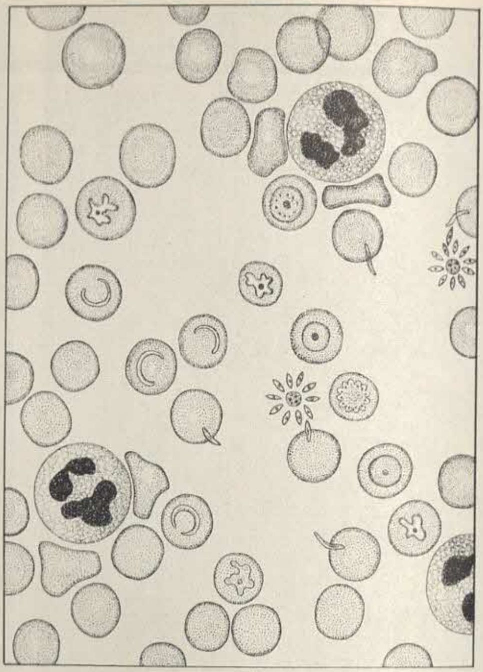
Scientists place these tiny animals in a group called *protozoa* (*proh*-toh-zo-a), which means "first animals." Paramecium is a member of this group. Most of them live in water. Protozoa are found more often in warm climates. The people of tropical Asia, Africa, and Latin America are frequently the victims of diseases brought on by certain of these unseen animals.

The common ameba, another of the protozoa, is found in warm, stagnant water. Like any other living organism, the ameba moves, takes in and digests food, uses oxygen obtained from its environment, gets rid of wastes, and reproduces its own kind. The Dysentery ameba is the major cause of diarrhea in warm climates. How do you suppose it gets into the human body?

The picture shows the structure of the common ameba. It moves by changing its shape. Can you explain this?



The malaria protozoan is carried by the female Anopheles mosquito.



Drawing of malaria protozoa invading human blood cells

Another kind of protozoan causes malaria. Scientists and doctors have wondered for a long time how the tiny animal that causes malaria gets into the human body. By testing and experimenting, they found that the Anopheles (uh-NAHF-eh-leez) mosquito carried the little protozoan. How does this microorganism get into the human body? How might you stop this disease from being spread?

African sleeping sickness is caused by a protozoan that is carried and transmitted by an insect, the Tsetse (TSET-see) fly. The climax of the disease is infection of the brain and death usually results. Time and experience have proven that the best known method for prevention of both malaria and African sleeping sickness, is to kill the insects and to destroy their breeding places. What methods can communities use to bring this about?

Bacteria

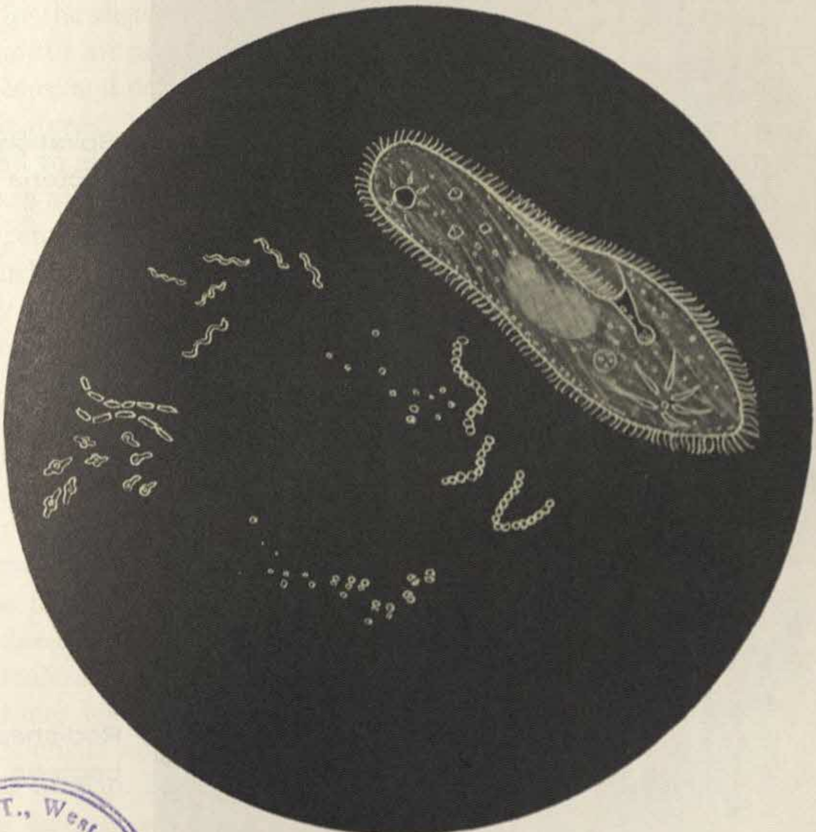
There are other groups of microorganisms which are plants, not animals. Some of these microscopic plants are green, but many are not. One of the non-green groups of plants, which you probably have heard much about, is called *bacteria.*

You cannot see bacteria with your magnifying glass. Some bacteria are so tiny that it would take 25,000 of them to make a line one inch long.

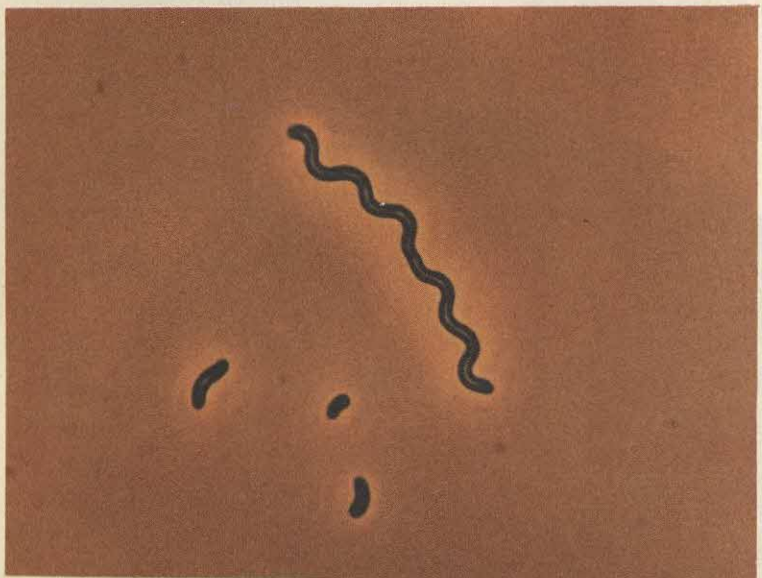
A drop of sour milk might contain 100 million bacteria! If you could observe these very small plants, you would find that some of them move about, while others never move at all. Some need air to live, while others will die if air touches them.

Bacteria are one-celled plants. They were first called "animalcules" (*an*-ih-MAHL-kyoolz) by Anton von Leeuwenhoek (LAY-vun-*hook*) in 1676. Why do you think the name was changed? Bacteria do not contain chlorophyll; therefore, they do not manufacture their own food.

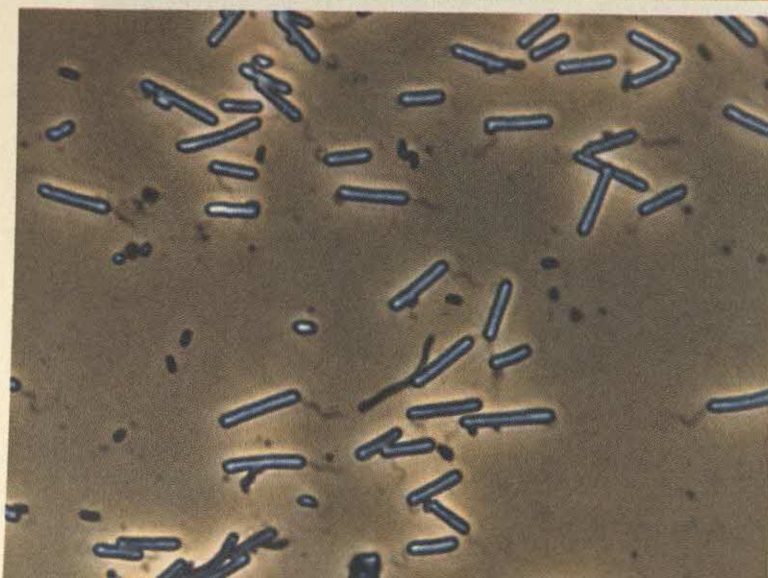
The microscopic structure of the plants you see around you is almost as organized as that of animals. If you examine the complex structure of a plant under a microscope, you will see organized cells. You can distinguish the different types of cells from which the plant is made. Bacteria are not always so well defined. Because of their small size, they are much more difficult to see.



Round bacteria



Spiral-shaped bacteria



Rod-shaped bacteria

Although there are many hundreds of different kinds of bacteria, they can be grouped according to three basic shapes:

Shape	Singular	Plural
spherical	coccus	cocci
rod-shaped	bacillus	bacilli
spiral-shaped	spirillum	spirilla

There are about two thousand known kinds of bacteria. There is hardly a place on earth where they do not exist. They are found on plants, on the skin of animals and man, in the digestive tubes of animals, in the air taken in by all living organisms, and on food eaten by living creatures. Not all bacteria are harmful to man. In truth, most bacteria are harmless and often helpful. For example, certain types of bacteria help to produce decay in dead matter, which returns valuable substances to the soil. Many pleasant food flavors are the result, in part, of bacterial action. Harmless bacteria enrich the flavors of cheeses, meats, cream, and other foods.

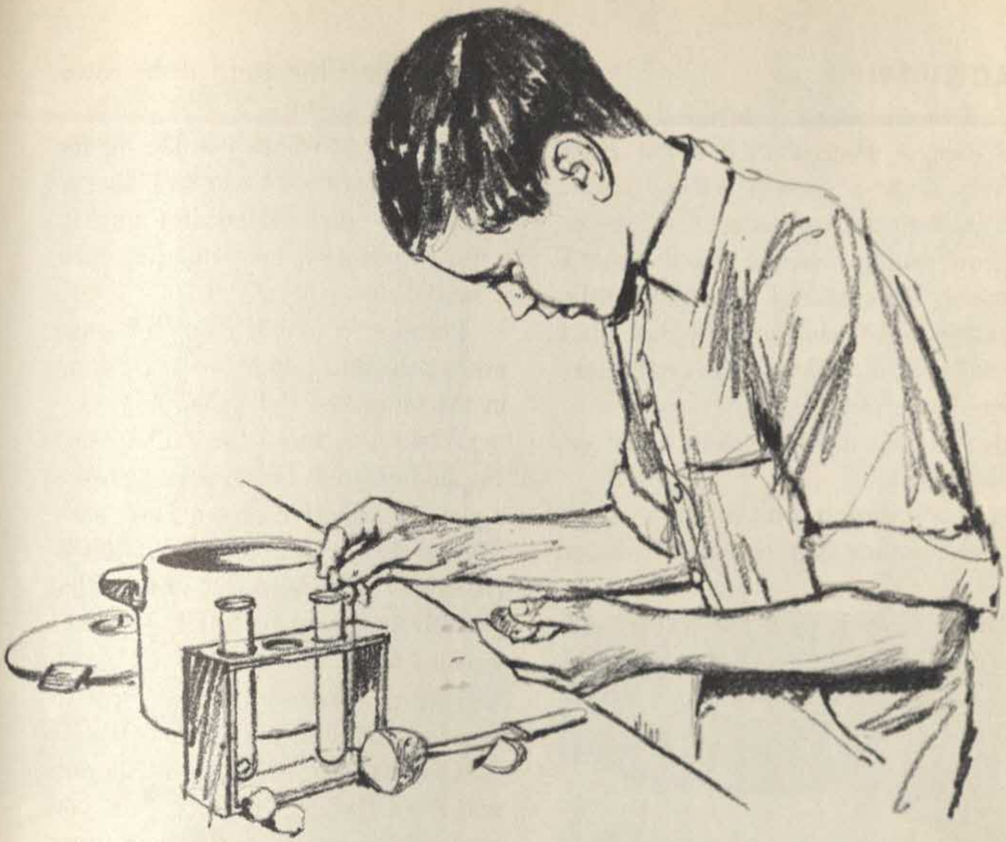
Only about one hundred kinds of bacteria are thought to be harmful. Of the harmful bacteria, some produce disease only in man, some only in animals, and others only in plants. Sometimes bacteria that are harmful in animals will produce the same disease in man. Do you know some of the diseases which man can get from animals? What are some diseases caused by bacteria?

Because a bacterium is so small, too small to see as a simple organism under your microscope, you will have to study them after they form groups of cells called *colonies*. This can be done because they often form differently shaped colonies, and many colonies are of different colors. Bacteria also live on different substances. This also helps identify them.

EXPERIMENT

Before you study about bacteria, it will be necessary to grow them. Obtain a beef bouillon cube and mix it with warm water. Add a spoonful of sugar, and you will have a liquid upon which certain bacteria will grow. A preparation of this kind is called a *culture medium*. Place some of this liquid into two test tubes and cap each loosely with cotton. Set them upright in a stand inside a pressure cooker and boil everything for at least 15 minutes. Why do you suppose this step is necessary? Save these test tubes for examination.

Take the balance of your beef broth culture medium and pour it into four test tubes which have been sterilized. A sterilized object is one that has had all microorganisms on it killed. Leave two test tubes open and place sterile cotton plugs into the other two. Observe what happens to each during the next few days. Does something happen in every tube? Do bubbles appear in some of the test tubes? How can you explain the differences in each test tube? Why were you asked to use *two* open and two closed test tubes instead of just one of each?



At one time people thought that bacteria came from non-living objects. What do you think? Are you able to prove what you believe? Perhaps this activity will help you.

EXPERIMENT

Instead of the liquid which you used in the previous experiment, you can use a few small pieces of uncooked potato. Drop a piece in each of two test tubes. Add a few drops of water and put a cotton plug in each tube. What purpose does the potato serve?

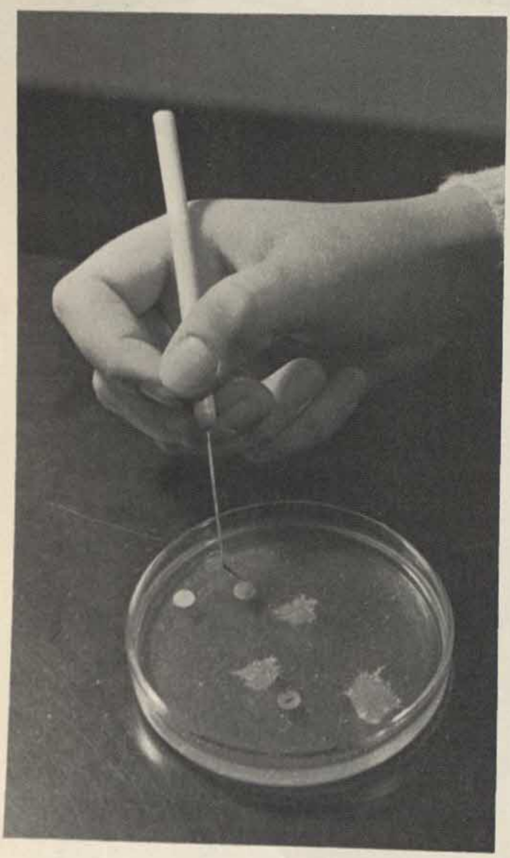
Now it is necessary to sterilize the test tubes. Put them into a pressure cooker or a double boiler. If you use a pressure cooker, boil the test tubes for at least 15 minutes. If you use a double boiler, boil them for an hour. This will sterilize the test tubes.

Place the test tubes in a test tube stand or rack. Take the cotton plug out of one and leave it open for about 15 minutes. Do not touch the other test tube. Return the cotton plug and observe the tubes for the next few days. Do you see any difference in the tubes? Why did you need two test tubes instead of one? Do you think living organisms come from non-living objects?

ACTIVITY

Obtain some sterilized Petri dishes. A Petri dish is a flat glass dish with a loosely fitting cover. These dishes are commonly used to grow bacteria. Inside the dishes is a moist food material. Do not open the dishes until you have decided what you want to put into each one. Here are some ideas.

1. Place a hair in one dish; cover and label it.
2. Put a thumb print on the medium in another dish; cover and label it.
3. Cough into the third dish; cover and label it, too.
4. Expose another dish to the air for 30 minutes; then cover and label it.
5. Keep one dish closed and label it. What purpose does this last dish serve?



How would you describe these colonies of bacteria?

Perhaps you can think of some other things to touch to the medium in the sterilized Petri dishes.

When you have finished closing the lids of your Petri dishes, fasten a piece of adhesive tape around each dish to seal it completely. DO NOT OPEN THEM AGAIN! Why is this precaution necessary? It is very important for you to wash your hands thoroughly whenever you work with bacteria. Do you know why?

Observe each dish after one day and record what you see. Can you count the number of different types of organisms growing in each dish? Are they all the same color? Can you estimate the number? Which dish has the most? Are you surprised?

Compare your results with those of your classmates. Did any organisms grow in your control dish?

EXPERIMENT

Obtain ten additional sterilized Petri dishes. Arrange them in pairs. Expose two dishes at a time to four different objects found in the room. This will provide you with eight Petri dishes which have been subjected to bacteria. Two unopened dishes will serve as controls. For each

of the objects to be tested, place one of the dishes in a refrigerator and the other in a warm, dark place. Be sure to put one of your control dishes in the refrigerator and the other in the same warm, dark area. After one day has passed, examine all of the Petri dishes. What do you observe?

Under what conditions do bacteria grow best? Try to design additional experiments to help you answer these questions. □□

Since bacteria can be found almost everywhere, it appears that they can survive cold or hot temperatures and many other unfavorable conditions. Many types of bacteria form tiny structures called *spores*. These tiny structures reproduce new bacteria. Spores can withstand unusual conditions and, when the conditions become favorable, they grow into new bacteria. For this reason, if you want to sterilize an object, it is necessary to heat it to a very high temperature and allow it to remain at that high temperature under pressure for at least 15 to 30 minutes. This will insure that any spores on the object will not be capable of growing into new bacteria.

EXPLORE

Obtain two small unopened containers of milk. Place one on a window sill in your classroom and the other in a refrigerator. Write the date on the outside of each container. Do not open either container for two days. After two days, open the top of each and smell the milk. Describe the smell in each container. What effect does lowering the temperature have on the microorganisms in the milk? What other conditions will slow down the growth of bacteria?

It is important to know how to prevent the growth of certain types of bacteria. Do you know why?

EXPERIMENT

Get some powdered milk. Place one-half of the contents in a small jar and add water according to the directions. Pour the rest of the powdered milk into a second jar. Keep this jar dry. Place both on a window sill in your room and leave them there for a few days. When opened, do they both have the same odor? How does the removal of water affect the growth of bacteria?

COMPARE

Collect some pond water. Pour one-half of the pond water into a beaker and boil it for 20 minutes.

Immediately seal the beaker with a piece of plastic sandwich wrap and a rubber band. Seal the remaining unboiled pond water in another beaker and allow the beakers to stand for a few days. Do you notice any differences in the two beakers? Is there any change in the contents of the two beakers? Open the beakers and smell the contents. Is there any difference in their odors? Can you give an explanation for your observations? □□

There are other ways to kill or prevent the growth of bacteria. Scientists have been searching for chemicals to stop or slow down the growth of bacteria, but they must make certain that the chemicals they use do not harm people. You can now experiment to see how some of these chemicals work.

EXPLORE

Bring a small amount of toothpaste from home. In your class you should have several different brands of toothpaste. It will be up to you to see which toothpaste does the best job of keeping bacteria from growing.

Obtain some sterilized Petri dishes. You have already seen how much growth occurs in them when you leave them open to the air for 30 minutes. Place a small amount of 4 or 5 different toothpastes into separate Petri dishes which have been exposed to the air for 30 minutes. Put the lid on the dishes and seal them with adhesive tape.

In a few days you should be able to determine which toothpaste contains a chemical with the greatest effect. Notice that there is an area around each spot of toothpaste which is free from bacterial growth. What does this area tell you about a particular toothpaste? Which toothpaste seems to do the best job? What happens when you place all of the different toothpastes in the same exposed Petri dish? Do you get the same results? Why must experiments such as this be repeated many times before the results are accepted?

OBSERVE

You might like to try a similar activity. Use separate dishes and use a toothpick to scrape some material from between your teeth. Make a line on the Petri dish with the toothpick. Add some toothpaste and seal the dish. Do the same for several dishes, but use a different toothpaste and a clean toothpick each time. Place the dishes in a warm, dark place, such as a closet or a desk. Leave the dishes for a week.

Observe the dishes after a week's time. Do you notice a clear zone in each dish? Do you see why it is important to brush your teeth after each meal? What would happen to food particles if they were to remain in your mouth for a long period of time? What do you suppose would happen to your teeth?

Is there another way in which the growth of bacteria can be stopped or slowed down?

EXPERIMENT

Select three apples of the same variety and about the same size and condition. Take a knife and cut a small slit in two of them. Let one remain exposed to the air. On the other, place an adhesive bandage. Allow the three apples to remain on a window ledge for a few days.

What do you observe on each apple? Is there any difference between the two apples you cut? Did the bandage have any effect? Why did you need three apples?

Repeat the above activity, but this time place some iodine or merthyolate on the cut of one apple. You can then place a bandage over the cut on each apple to see if the antiseptic helps to slow down the growth of bacteria. What did you observe? How do antiseptics help to protect you when you are cut?

INVESTIGATE

Here is another experiment that will add to your knowledge of bacteria. Obtain three beakers and three pieces of glass to cover the beakers. You can, instead, use jars which have lids.

To a quart bottle of water, add three tablespoons of mineral fertilizer. Shake this mixture and allow it to stand.

While the mixture settles, add about one-half inch of soil and half a teaspoon of sulfur to one of the beakers. Pour some of the water containing fertilizer into the beaker to a level about one inch above the soil. Swirl the liquid around and cover the beaker.

To the second beaker, add the same amount of fertilizer solution and soil, but do not add the sulfur. Cover the beaker.

To the third beaker, add the fertilizer solution and sulfur, but do not

add the soil. Cover this beaker too.

Now allow the three covered containers to rest, undisturbed, for about two weeks. Keep a careful record of any changes you notice in any of the beakers.

Why did you need three jars? What conditions were different in each container? Did you see similar changes in all the jars? Did you notice a different odor in each of the jars?

In which jar did bacteria grow best? Why? What did this experiment teach you about bacteria?

OBSERVE

In this activity you will be able to observe two types of bacteria.

How does air affect bacteria?

Obtain two coffee tins or wide-mouthed jars. Into one tin, add about one inch of soil. To the other tin can, add one-half inch of soil.

Prepare a mixture of water and fertilizer by mixing ten teaspoons of mineral fertilizer in a quart jar of water. Dip a piece of filter paper into the mixture of water and fertilizer and place it on top of the soil in the first tin. Pour the remaining water into the second tin. Cover the first with a lid. Leave the other open. Let this experiment continue for two weeks.

What happens to the paper? Would the same results happen if you used plain water? How could you find out? Are the organisms in each container the same? □ □

Some bacteria need air for growth. These are called *aerobic* (air-RHO-bik) bacteria. Other bacteria grow without air. These are called *anaerobic* (*an*-air-RHO-bik) bacteria.

Septic tanks make use of the anaerobic bacteria to change waste products into harmless material. Because anaerobic bacteria do not require oxygen, they do this work very well.

In earlier activities you learned that some bacteria do not need air in order to live. Bacteria are living organisms, however, and they must ingest and digest food to sustain life.

In this activity you will see if all these microorganisms use their food in the same way.

EXPERIMENT

Obtain two quart-sized, wide-mouthed jars. Prepare two quarts of a fertilizer solution as you did in the previous activity.

Mix about one ounce of powdered unflavored gelatin with a cup of garden soil. Protein is an important part of food. It is present in lean meat, cheese, milk, jello, and gelatin. Place the mixture in a quart container. Label the container "Protein."

Carbohydrate is an energy food. It is present in sugar, bread, flour, potatoes, and starch. Mix one ounce of sugar or starch with one cup of garden soil. Put the mixture in a quart container labeled "Carbohydrate."

Fill each container with the liquid fertilizer mixture. Let the mixtures stand for two to three weeks. Begin keeping a record of what you observe after the second day. Watch for the appearance of colors and odors, and the development of growths. Were the growths in the containers different? Is oxygen present? What do we call bacteria that live under these conditions? □□

Certain bacteria break down protein food. What name might be given

to this kind of bacteria? When proteins are broken down, the process is called putrefaction (*pyoo*-treh-FAK-shun).

Other bacteria break down carbohydrates. What might they be called? The breakdown of carbohydrates is called *fermentation* (*fur*-men-TAY-shun). See if you can create experiments to solve the following questions.

Does light have any effect on fermentation or putrefaction?

Alexander Fleming

Would different soils have any effect?

What effect does heat have?

Would fermentation and putrefaction take place if air were present?

Would different amounts of food or soil have any effect?

What would happen if you added a large amount of salt to each mixture?

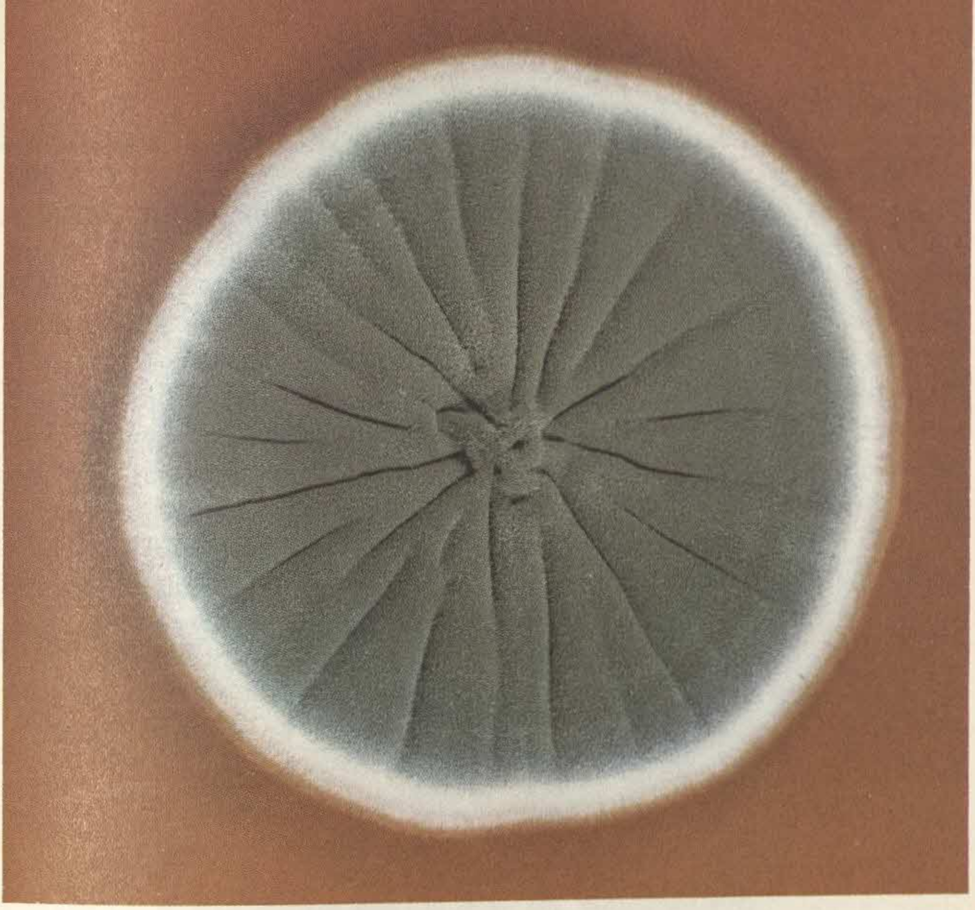
Before trying any of these experiments, guess what you would expect to happen. Then do the experiment to see if your judgment was correct.

When bacteria live on or in man, plants, or animals, the bacteria are called parasites (PAIR-a-sytes). What diseases do we get from these bacteria?

There are other bacteria that live only on dead material. They are called *saprophytes* (SAP-roh-fites). Saprophytes are not normally found in any part of the human organism. Can you tell why?

Molds

Molds are a common form of "non-green" plant. The words "non-green" are used here to describe plants which lack a green substance called *chlorophyll* (KLOH-roh-fill). Some molds are actually green in appearance, but lacking chlorophyll, are called non-green. Molds are valuable in the manufacture of some beverages and cheese, and in the production of penicillin, a medicine that is often given to combat infection.



Penicillin

Penicillin comes from a mold similar to the one that forms on fruit when it is left standing for a time. Sir Alexander Fleming discovered penicillin in 1929. Fleming was growing some disease-causing bacteria in his laboratory. He noticed that a particular kind of green mold was growing near the bacteria. When he looked at it closely, he saw that the bacteria seemed to dissolve near the mold as the bacteria had dissolved near the toothpaste samples in one of your experiments. Fleming experimented with a sample of the mold and found that it would destroy certain types of bacteria that cause disease.

Some harmful molds cause disease in plants and make the plants unusable to man. The rot of peaches, plums, potatoes and grapes, and the mildew on old fruit are a few examples of the destructive ability of molds. Some molds are extremely valuable to man. Without helpful molds and bacteria, essential materials could not be returned to the soil. Growing healthy fruits and vegetables would be impossible.

Growing Molds

OBSERVE

Molds are grown rather easily. Get a coffee can or other container which can be sealed. Place a moist blotter or paper towel on the bottom. Take a piece of white bread and place it on the blotter in the can. Leave the can open for about 30 minutes and then close it. Place your name on the outside of the can and store it in a closet for about one week.

Molds cannot make their own food. They must grow on dead plants, animals, or their products. When they grow on grapes, oranges, or other foods, they become a nuisance. Certain other microscopic non-green plants can attach themselves to the outside of your body and cause disease. Ringworm and athlete's foot are two such diseases.

Molds reproduce by forming tiny seed-like structures called *spores*. The spores of different kinds of mold are often of different colors.

Scientists can often identify the species by looking at the color. When a spore lands on a substance where growth conditions are favorable, it begins to grow into a mold. Spores are so light in weight, they can be carried by the wind for hundreds of miles.

Open your container and look inside. What do you see? Look carefully and try to count the number of different kinds of mold you have in your container. Look at your neighbor's container. Does he have as many different kinds as you do?

You will probably see a black, spore-producing mold in your container. This is a common variety of mold. It is called black bread mold. Examine this mold more closely, using a hand lens.

Take a glass slide and put a few spores on it. Look at the spores through a microscope. What do they look like? Draw a picture of what you see. How would you use your microscope to learn more about molds?

INVESTIGATE

What are the conditions favorable for the growth of mold? Set up a series of experiments to find out. Do not forget to control such factors as light, moisture, temperature, and the various nutrients found in foods. See what effect each of these factors

Some molds are helpful and some are harmful.

has on the growth of molds. After you have tested each factor, you should be able to report on the best conditions for mold growth.

Will the same molds grow on different foods? How do fruits and vegetables become infected with molds? Can fruits and vegetables resist infection?

To answer these questions, bring to class several samples of moldy food. Perhaps you can find an orange with green or blue mold covering part of it, a sweet or white potato with black mold on it, an apple with a brown spot, or a carrot with a soft moldy area. You may have to grow these molds yourself.

ACTIVITY

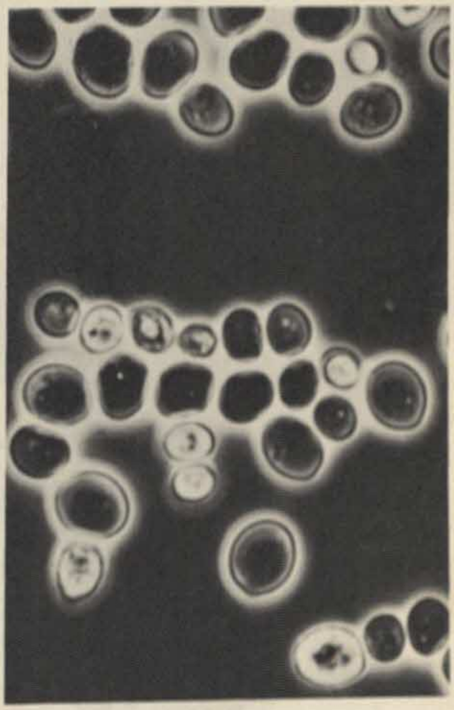
Place different kinds of healthy fruits and vegetables in small bowls or cans which can be covered. Jab a needle or stiff wire into the moldy section of one of your samples. Then jab the same needle into a piece of the "healthy" food. Cover the container. Wait one week and observe the contents of the containers. What do you see?

Scrape some mold onto the skins of other portions of food and cover the container. Do not disturb this container for several days. Then observe the food. What do you notice?

How do molds get started in fruits and vegetables? Do different fruits and vegetables react differently? Do the same molds grow on different foods? □□

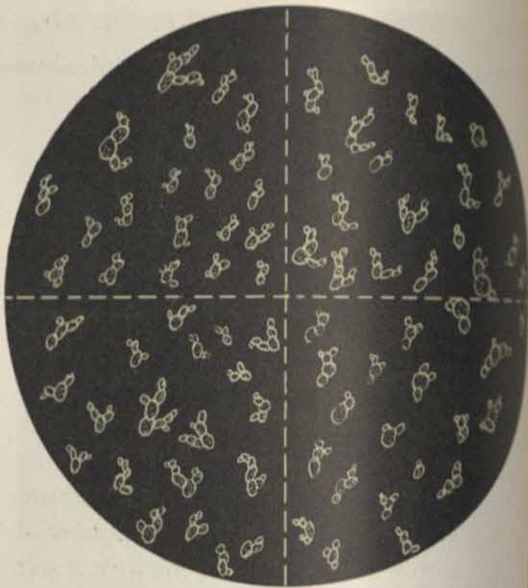
Yeasts

Yeasts are living things, similar to bacteria, molds and mushrooms in that they are non-green. Have you ever seen yeast growing? Probably you have not, but years ago when people made their own bread, yeast was combined with flour, water, and sugar to form the dough. When these ingredients were mixed and allowed to stand, the dough would rise. This would happen because a piece of yeast contains a mass of very tiny living plants called yeast cells. These plants live and grow very rapidly on sugar. It is their presence in the bread mixture as they give off carbon dioxide that make dough rise.



Yeast cells greatly magnified

Like the mold, the yeast plant does not contain chlorophyll, the green coloring matter of plants, to carry on photosynthesis. Because of this, yeast cells cannot make their own food. Do you know how green plants make their own food?



OBSERVE

Prepare a mixture of yeast, sugar, and warm water. Allow this blend to stand for about an hour. Take a glass slide and place a drop of the mixture on it. Lay a cover glass on the drop and put it under your microscope. Focus the microscope until you see the yeast cells. Observe them carefully. What do yeast cells look like? Keep observing for several minutes. Does anything seem to be happening as you watch? Can you guess the number of yeast cells in your field? How might you check your guess?

One way to estimate the number of cells in a field is to divide the field mentally into fourths. Count the number of cells in one quarter of the field and multiply the number by four. Compare your estimate with those of your classmates.

Let the mixture stand overnight. Can you estimate how many yeast cells might be in your field tomorrow? Make a good guess, then look at the same mixture twenty-four hours later. Were you right? These tiny yeast plants are in the air almost everywhere. Why are they usually not seen?

ACTIVITY

Take a piece of baker's yeast and drop it into a small bottle. Add a little molasses and water. Shake the mixture.

Get a one-hole stopper and insert a piece of glass tubing through it. Be careful not to push too hard for it may break. It will be easier if you wet the glass tubing before you press it through the stopper. Attach a small piece of rubber tubing on the end of the glass tubing.

Pour some limewater into another small jar. Put a two-hole stopper into the limewater jar and insert two small pieces of glass tubing into the stopper. One piece of the tubing should be placed into the limewater; the other should be above it.

Attach the rubber tubing leading from the first jar to the glass tubing which has been placed in the limewater. Let the equipment stand for 24 hours.

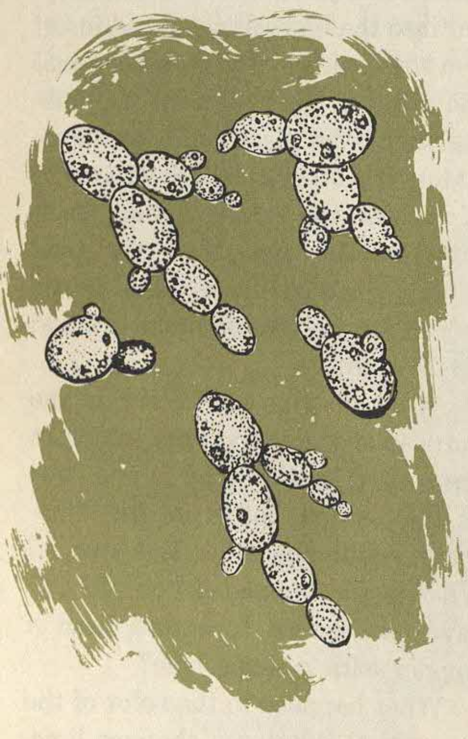
What do you see? What is the purpose of the extra glass tubing in the second bottle? Why is one tube of the second bottle in the limewater, while the other is above it? What would happen if you did not have the second tube and used a stopper with a single hole?

What happens to the color of the limewater? What gas changes limewater in this way? Open the first

bottle and smell it. What kind of odor does it have?

Take a drop of the liquid from the first bottle and place it on your slide. Put it under the microscope. What do you notice? Watch it for a few minutes. Does the number of yeast cells increase? □□

The process of yeast-dividing is called *budding*. Budding is a special type of reproduction that involves only one parent. The tiny bud cells grow and remain attached to the larger parent cell for a short period of time. Eventually they break off. If you observe yeast cells carefully, you can see this kind of reproduction.



Fermentation is the process of sugar being changed into alcohol and carbon dioxide. Yeast cells can cause this chemical reaction. When yeast is added to sugar and water, and the mixture is allowed to stand in a warm place, the fermentation takes place quite rapidly. What evidence do you have that yeast cells form alcohol? How did you prove that yeast cells give off carbon dioxide during fermentation?

Viruses

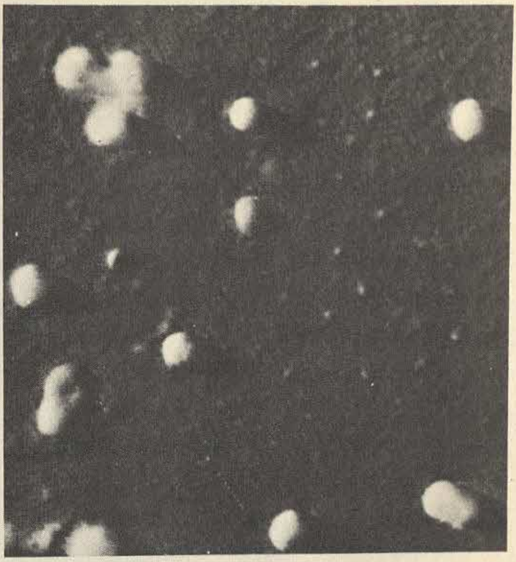
Knowledge about viruses has increased greatly in the last twenty-five years. The invention of the *electron microscope* about 1935 has made this possible. The electron microscope is one of the most important developments in modern science. The most powerful lens microscopes can magnify an object 2,500 times. If a special camera is attached to the electron microscope, the object can be magnified over 200,000 times.

Viruses, the smallest microorganisms known to exist, can now be inspected and observed. Many scientists believe they are an important link between living and non-living matter. Compared with the tiniest bacteria, viruses are thousands of times smaller. Even filters designed to strain out bacteria do not hold back viruses.

It seems reasonable to judge organisms as living by their ability to reproduce their own kind. Are non-

living objects capable of reproducing themselves? Experiments prove that viruses do reproduce their own kind, but only inside a living cell. Knowing this, it is difficult to say definitely that viruses are living organisms.

The viruses must have living tissue on which to live and multiply. Once a virus invades a cell of human, plant, or animal tissue, it lives on that cell and begins to multiply immediately. An infectious disease usually follows. Virus diseases, therefore, do occur in plants and animals, although viruses that are infectious in one species do not usually attack an organism of another species.



Influenza virus magnified 110,000 times

Viruses can only be seen with an electron microscope.

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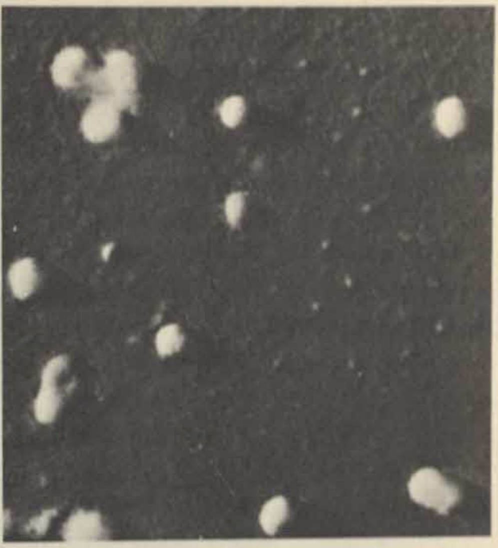

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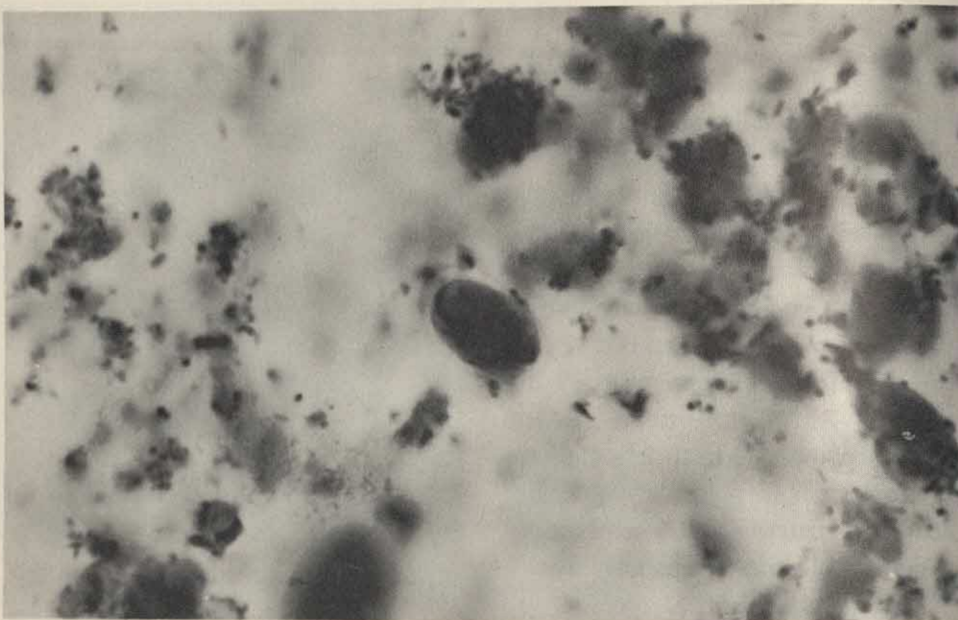


Rickettsia

(General Biological Supply House, Inc.)

Viruses have long inhabited the earth but specific knowledge about them is considerably new. Epidemics of measles, polio, smallpox and yellow fever were known centuries ago. Millions of people have perished from viral diseases over the years. Today vaccinations have decreased man's chances of contracting many virus diseases. In recent years much research has been done to confirm the possibility of a virus causing the common cold, but no definite conclusion has been reached.

Some scientists say that the presence of virus particles may be the effect of a disease rather than its cause. There is still much to be learned about these strange tiny particles.

Rickettsia

Rickettsia (rick-EHT-sih-uh) are small organisms that are seen only with an electron microscope. They are very much like bacteria in appearance. In size, however, they are smaller than bacteria but larger than the viruses. Harmful rickettsia, like viruses, multiply on living material.

Rickettsial diseases, characterized by high fever, are transmitted to man by lice and ticks.

Diseases

Since early times, men have been tormented by diseases which are caused by some of the microscopic plants and animals you have been studying. From your reading, you probably know much more about the

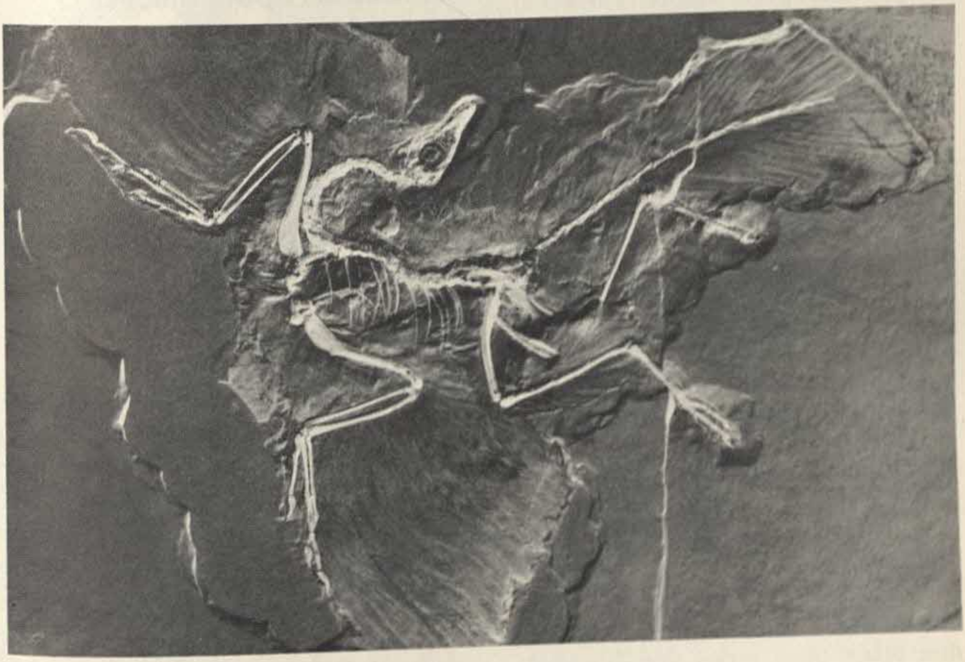
cause and prevention of disease than many of the earlier scientists.

Diseases were very mysterious to early man. He often noted their symptoms but did not know what caused or spread them. Thus he was unusually afraid of illness. Through the years man's knowledge about disease has increased. As he gained more understanding by observing, testing and experimenting, he began to lose his fears, and to learn better ways to control diseases.

Early Evidence of Disease

Scientists believe that it is important to base your beliefs on evidence. Observation and experimentation are ways to gather evidence. How can we find out about the diseases that troubled man in the distant past? About 5,500 years ago, the invention of writing made it possible for men to record their experiences in permanent form. Some of the earliest writings on medicine, however, date from about 1570 B.C. and originated in Egypt. We must rely on other kinds of evidence when investigating earlier times.

Today's scientists believe that microorganisms, similar to the ones alive now, were probably present thousands of years ago, and that they might have infected man. The evidence comes from the remains of prehistoric man which have been preserved and found. The remains or traces of ancient creatures and plants found buried in earth or imbedded



How do you think this fossil was formed?

Human fossils sometimes show signs of disease.

in rock are called *fossils* (FAHS-uls). Microscopic examinations of these discoveries help to confirm the existence of certain microorganisms.

Fossils of man found in Europe provide evidence that people may have had tuberculosis twelve thousand years ago. This indicates that tuberculosis may be at least that old. One skeleton of a prehistoric man shows that he may have had poliomyelitis. The work probably done by bacteria can also be observed on fossil fish and animals. Some of these animals show evidence of diseases which still exist. Decayed teeth, a common find, also provide evidence for ancient bacterial action. These and other discoveries are the scientific evidence of early disease.

Early Ideas About Disease

How do you suppose early man explained disease? Without written records we can only construct a reasonable explanation to fit the facts. Fossils of early man indicate that there was a rather common and widespread practice of cutting a hole in the skull. One explanation for the practice is based on the ancient belief that disease is a product of evil spirits. By cutting a hole in the head such evil spirits would be freed. Another theory suggests that an operation was performed to actually heal head wounds by relieving pressure. Whatever the reason, this early surgery must have been very painful without the use of anesthetics, the modern pain killers.

Early medicine was linked to religion. Evidence collected in the Middle East, Egypt, and Peru shows that disease was commonly explained by supernatural causes. Prehistoric man probably believed that the air was filled with demons and devils that produced disease. These could attack humans when the gods, possibly made angry by some sin, removed their protection. The sick person was often thought to have an evil spirit in him.

Where disease was believed caused by such unearthly powers, it would seem natural for people to wear charms to guard against the bad spirits and win the favor of the good ones. Perhaps these people considered the piece of bone that was removed from the skull a kind of charm. Have you ever carried a rabbit's foot? What other good luck charms are popular today? As you may have guessed, many of our superstitions originated in ancient practices.

Why does this witch doctor wear such a frightening mask?

Thus primitive man sought ways to obtain relief from pain and cure disease. When the charms failed, the "witch doctor" was called in to find a cure. He explained what he thought were good and bad signs and, with mask and painted skin, conducted a ceremony. Saying his "miraculous" words, he might rub a special charm on the person's troubled part. He might give a magic drink. He might even conduct a sacrifice!

Although nothing is known with certainty about the medical practices of prehistoric people, there is another way of forming ideas about their behavior. In certain parts of the world—Australia, New Guinea, South America—very primitive groups still exist. Studies made among these isolated tribes reveal a belief in a supernatural cause of disease.

While perfecting tools, weapons, wheels, and the use of fire, while trying to keep and raise animals and grow plants, he never dreamed that tiny plants and animals were causing many of his troubles. Many cen-

turies passed, empires rose and fell, before mankind found answers to the questions related to disease.

Early Treatments

Blood-letting was probably another early means of getting rid of the "demons" from the body of an ill person. People of the Stone Age might have believed that if evil spirits entered the body, they must be given the chance to leave or to be forced out. To accomplish this, they would cut a part of the body and allow the blood to flow freely for a period of time. They would then get rid of the blood by burying it in the earth. It was a common belief that all waste and remains from the body must be disposed of in the same manner. Can you see how some of these customs actually helped to improve conditions, though they did not cure diseases? By releasing blood from the body, pain and pressure were sometimes relieved. Until rather recent years, this method was often prescribed by doctors.

By separating the sick people from the healthy, by burning and burying refuse, and by burying the dead in special places away from

the community, early man unknowingly prevented the spread of disease. Unfortunately, some primitives had little respect for a sick person, and we have reason to believe that they often burned the sick person with his belongings.

These earliest methods of handling disease were continued and improved by the Egyptians, the Greeks, and the Romans in later ages.

Early Progress

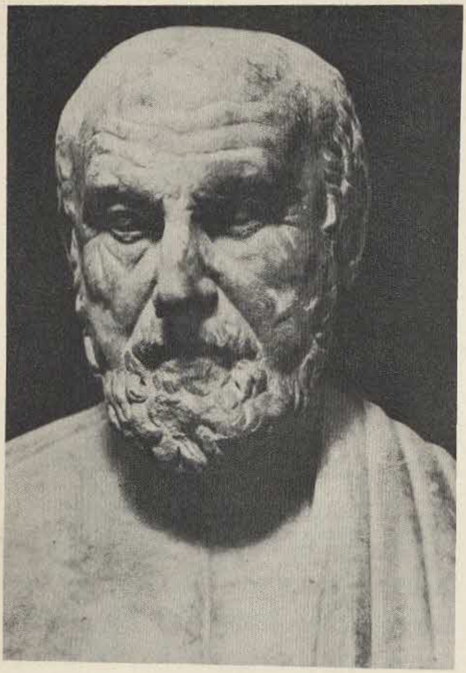
Primitive man had little of the opportunity to grow in knowledge that we have in modern civilization. His theory that disease was the work of a magical or supernatural force would not lead him to look for the natural causes of sickness and the reasons for health. Even among civilized people like the ancient Egyptians, disease was associated with gods and magicians. Magicians, in this sense, were men who were able to "cast a spell" on the evil spirit producing the disease and, in this way, drive the spirit from the sick person.

The Egyptians gave drugs to the sick. Why do you think they would do this? Is this practice related in any way to the work of modern medicine? The answer is yes and no. For the drugs were given in the belief that they would prove unpleasant to

the evil spirit causing the disease and that he would leave. Like the modern doctor, the Egyptian magician believed that there was a relation between cause and effect. He was wrong, however, about the causes of disease and wrong about the effects which would be produced by his magic potions. Modern medicine is founded on the idea that every disease has a cause, and that the doctor, by his drugs, surgery, and other proven methods, can have some effect on it.

The Egyptians also believed that man was immortal. Before the dead were buried, their bodies were carefully prepared for preservation. Later on in their history, the Egyptians even learned how to embalm the dead. Some of these carefully prepared bodies, known as mummies, have come down to us. There are cases where the diseases of the dead persons have been identified by modern experts. In the later written records of the Egyptians, dating from about 1500 B.C., diseases were given names, and there were prescriptions on how to cure them.

Egyptian doctors generally tried to use magic and other such practices to drive out demons that they believed were the cause of disease. Later in the history of Egypt, the doctors tried to understand and cure



Hippocrates

disease by natural means. They realized, for example, that broken bones could not be cured by magic or charms.

The Greeks

In ancient Greece, as in ancient Egypt, there were many superstitions. But there were also a number of men who used their reason to explain disease. One of these men, Hippocrates, was so remarkable that he is known as the "Father of Medicine." He was born about 460 B.C., and although little is known about particular events in his life, there is evidence that he traveled widely and achieved great fame. His writings are known as the "Hippocratic Collection."

Why is Hippocrates called the Father of Medicine?

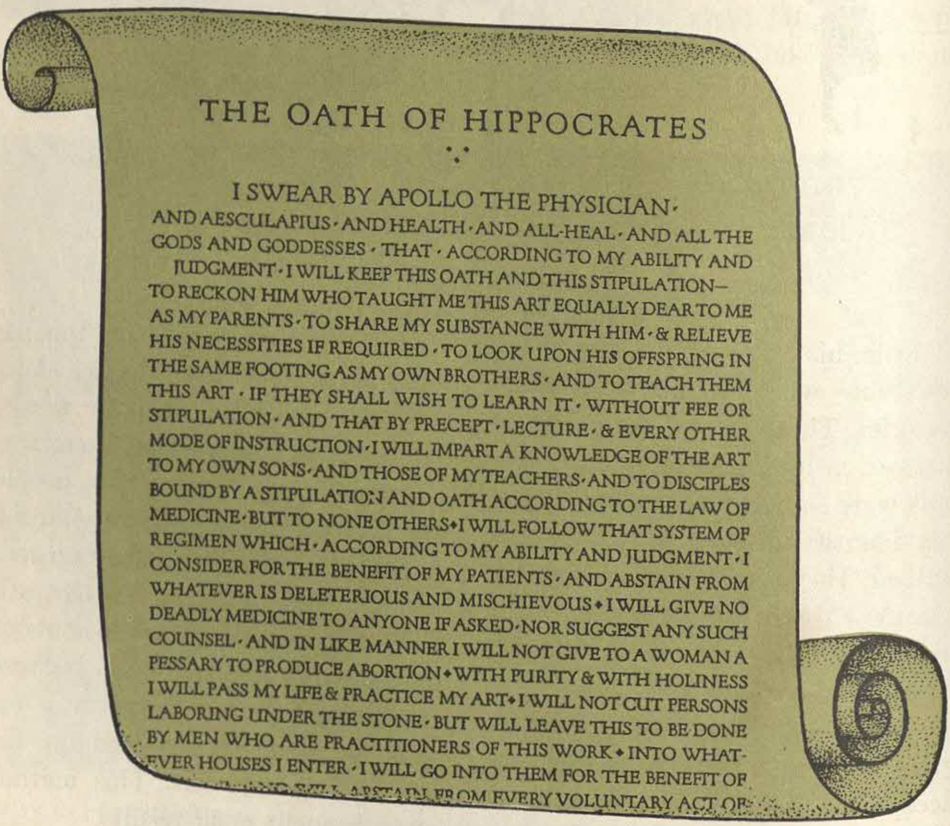
From his observations, Hippocrates wrote what we now call case-histories. These were descriptions of diseases in his patients, and his records were so accurate that today we can identify diseases which he described. He was able to predict for a patient the future stages of his illness, even though he often could not cure the disease.

The Greeks were one of the first great nations in history to construct acceptable theories to explain things that they observed. One of these theories said in part that "the patient must combat the disease along with the physician." In other words, Hippocrates claimed that there was a healing power in the sick people themselves. He was also very strong in his belief that disease had no connection with magic and witchcraft. This was an entirely new idea about disease and its treatment because Hippocrates looked for natural reasons for what he saw and for the way sick people felt. This method often brought good results.

What he observed he called signs. The word *symptoms* is used by doctors today to describe the way a person looks and feels in time of sickness. Some common symptoms, or signs, of illness are fever, cough, pain and rash. What are some other ways your body lets you know that all is not well?

Hippocrates taught his followers to detect and treat disease by observing signs during the course of the illness. He considered how the person began to get ill, how he was at present, and what he could do to help him recover rather than hasten his death. He stressed the importance of understanding the disease itself. The writings of his followers are also included in the "Hippocratic Collection."

A great and courageous man, Hippocrates had a "deep affection for humanity and respect for the art of healing." His principles brought regard for the doctor who, until then, was often considered a magician or one involved in witchcraft. He established the idea that all disease has a natural cause, and it is within reach of man to discover that cause.



Hippocratic doctors realized the importance of the surroundings in which a person lived. They considered the individual's sanitary conditions, the kinds of food he ate, and the source of his water supply. Although nothing was known about microorganisms, his followers proved that it was best for a person to use clean boiled water when bathing open wounds and sores. They recognized infection and knew that it was something undesirable.

Much of the progress of Greek thought and the approach to medicine taught by Hippocrates was not used for many years. His principles were stressed again by Galen, another Greek physician who practiced in Rome a few centuries later. Indeed, it is remarkable that many of Hippocrates' ideas guide modern medicine.

The Romans

The Romans at first had little time to spend on methods to improve or prolong human life. Their territories were inhabited by barbarous groups, and Rome specialized in conquest and government. With the expansion of the Empire, the Romans learned from the Greeks and other conquered peoples. They learned a great deal about the body, especially the nervous and respiratory systems. They learned much more about drugs when the Western empire expanded into the East. But, in spite of these advances, medicine as a whole improved very little.

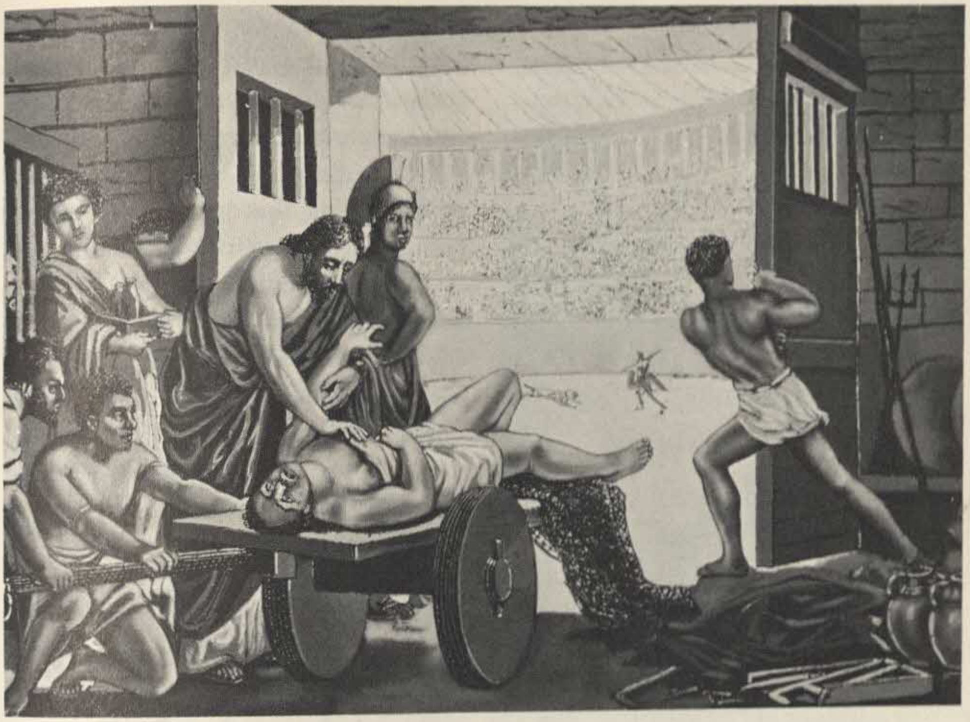
Attempts to cure disease were reserved mostly for the rulers of the Empire and the wealthy. For the general population, a "leave-it-to-nature" attitude was held. The wealthy had much in their favor.

Water was purified by filtering it through porous stone or sand before it was brought to their homes through aqueducts. The water served both for cleansing purposes and for flushing lavatories. Moreover, Roman engineers planned good drainage systems. As you can see, sanitation existed but not for the masses, whose living conditions needed improvement. The Romans failed to see a relationship between living conditions, working conditions, and health as did the Greeks. The result was that disease spread among the poor and working classes. With good reason these forgotten people had no faith in their doctors so they continued to rely on religious beliefs, herbs, potions, and superstitions. Bloodletting remained an old standby for cures.

Claudius Galen

During the second century, Claudius Galen, a Greek physician in the Roman Empire, made important contributions to medicine. His career had begun at 28, after 10 years of study, when he was appointed surgeon to the gladiators by the high priest in his home town. A few years

Roman engineers built this aqueduct to carry fresh water.



Galen treating a wounded gladiator in ancient Rome

later he had such fame in the city of Rome that he was called to examine the emperor himself.

Galen was probably the first to believe that blood moved in the body and could be found in the arteries. Before this, men believed that the arteries contained air. Galen, however, did not understand the circulation of the blood and more than 1000 years would pass before it was explained. Galen taught that the heartbeat was due to the action of the heart muscle itself, and that the blood vessels contracted and expanded with every pulse beat. From his experience with animals, he learned about the nervous system, and that injury to the brain may cause a person to lose the ability to move his body.

The common occurrence of infection after surgery led Galen to conclude it was something good and desirable. Writings during this period frequently refer to his theory of "laudable pus." From observing your experiments, would you agree with Galen? Why? Galen wrote numerous books about medicine which were held "sacred" for almost 1500 years, even though many of his ideas were false. Despite the errors, his greatness as a scientific observer, experimenter and doctor cannot be overlooked.

The Middle Ages

There was very little progress in medicine during the following centuries. However, a few individuals attempted to keep alive the knowledge that existed. See what you can learn about the contributions of such men as Nestorius, Dioscorides, Rhazes, and Avicenna. Can you find the real name for Avicenna? What can you find about the contributions of Roger Bacon?

Between the decline of the Roman Empire in the fifth and sixth centuries and the Renaissance of the fifteenth and sixteenth centuries, the Moslem Empire and Christianity grew. During this troubled time circumstances were not favorable for growth in medical science. Much knowledge would have been lost completely had it not been for the individuals previously mentioned and for the religious monks, acting as

scribes, who kept the wisdom of the ancients alive.

In the Middle Ages medicine and religion united wisely in the creation of hospitals to relieve suffering. Unfortunately, the people themselves failed to improve their health practices and the prevailing unsanitary conditions often resulted in disease. Dark, damp homes were sure breeding places for germs and insects. Crowded conditions in the cities brought neglect in the disposal of garbage and wastes. Water became polluted and unfit for use. Very deadly diseases called plagues were a common threat from which there was no escape. The Bubonic Plague alone, in the mid-fourteenth century, took one-fourth of the population of parts of Europe in one wave. Whole towns and communities were nearly wiped out.

After the so-called Black Death, a name sometimes given to the Plague of the fourteenth century, men became more conscious of the spread of disease. They could not see the microorganisms that caused the sickness, but they could observe the symptoms, the results, and the ways it might be spread. They noted that contact with a diseased person or with something belonging to him could result in disease. They formulated a rule stating that the person must be removed from community living. They set up special houses where victims of the plague were taken. There was no known treatment, but many rightfully felt they were saving others from the same fate. Thus the ill often had to depend on the charity of strangers. In time, governments demanded that all infections be reported. Health officers were hired and went from door to door checking for sickness. If they found disease, windows and doors were barred, and the individuals were

Victims of a plague

at the mercy of those outside for food and other necessities.

By the sixteenth century, it was felt that authorities had in their power the ability to control the spread of disease. Believing the plague originated in Asia, they took precautions with imports. Ships had to be treated with smoke or gas before coming into port to dock. Greater consideration was also given to the sun as a purifying agent. Articles were often exposed to sunlight and homes of the ill were open to the sun's rays for days before people were permitted to return. As a precaution, water was boiled before it was used for drinking or bathing. Doctors began to wear special clothes to protect themselves while treating patients with infections. An enthusiastic drive for general cleanliness was upheld. Generally, Europe struggled for better public health.

The Renaissance

With the coming of the Renaissance, a period of time roughly between the fourteenth and sixteenth centuries, men became more curious about the natural world and science. There was, for example, a deeper interest in the study of anatomy. The work of an artist, Leonardo da Vinci, in the last half of the fifteenth century shows this. To improve his art, he carefully studied the parts of the human body. Many of his sketches still exist today.

Men were also trying to set aside the ancient superstitions. Hieronymus Fracastorius (*frah*-kas-TAWR-ih-us), an Italian doctor at Verona during this same period, proposed a theory of "rapidly multiplying invisible 'seeds' of disease," centuries before bacteria were discovered.

Andreas Vesalius

In 1514, Andreas Vesalius (veh-SAY-lih-us) was born into a family of five generations of doctors. He is known as the "Father of Anatomy." Anatomy is the study of the structure of an organism. Vesalius had great zeal, energy, and curiosity about the human body and always treated it with utmost respect. As a teacher, he let his students study anatomy by dissecting animals themselves rather than letting them stand around and watch.

In 1543 he published a book, "The Fabric of the Human Body," which owes much of its greatness to its illustrator, Jan Stephen van Calcar. The drawings are among the most accurate and natural representations of human anatomy in existence.

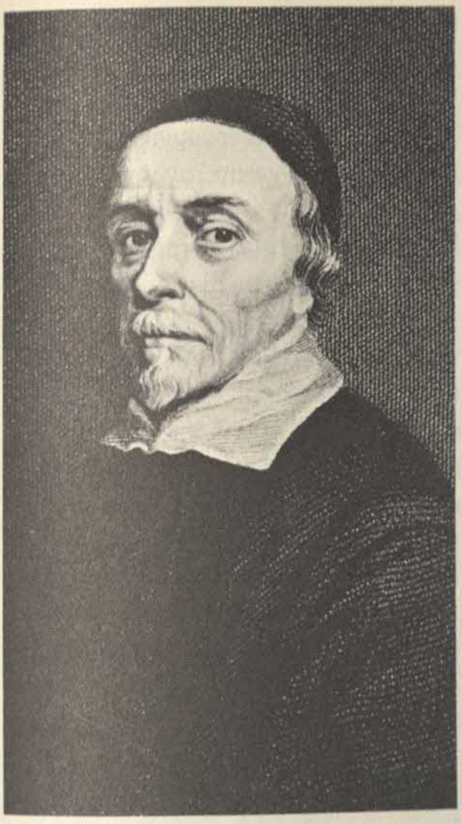
Andreas Vesalius studying human anatomy

The findings proclaimed by Vesalius shocked many people, but he had the courage to speak out against Galen's popular but false theories after proving they were wrong. Because of his new ideas, he was forced to withdraw from his position as a teacher and scientist. In 1564 Vesalius was shipwrecked and died soon afterwards. Although he died unknown and alone, his pioneering works continue to live on, for the investigation of human anatomy is a standard practice in medical schools today.

William Harvey

William Harvey, in 1628, published a book "On the Circulation of the Blood." It is considered one of the greatest works of the period although it contained only seventy-two pages. Harvey described the heart as a powerful hollow muscle responsible for moving the blood. He estimated that the heart pumped two ounces of blood with each heartbeat and that there were seventy-two heartbeats in a minute. He figured that the weight of the blood passing through the heart in an hour

William Harvey demonstrating the circulation of the blood



William Harvey

would be more than the weight of the whole body! Harvey wondered how this could be possible until he realized that the blood must be moving in a circle.

One thing he could not account for, however, was how the blood got from the arteries to the veins. The microscope had not been perfected at that time, and no connection of arteries to veins was visible without one. He did not know about the tiny capillaries. It was only after the discovery of the microscope that his question was answered.

MEASURE

You can make an instrument with which to measure the rate of your heartbeat. You will need a plastic funnel, a length of rubber tubing, a small balloon and a rubber band. Insert a plastic funnel into an 18-inch length of rubber tubing. Cut the neck off a small balloon and stretch the body of the balloon over the mouth of the funnel. You may fasten the balloon with a rubber band.

Count the number of times your heart beats in one minute while sitting, standing, and after exercise. Compare your results with those of your classmates. What is the average heartbeat for your class? Using your data, figure out the average number of times a heart beats in one year.

The first man to describe microorganisms

Anton von Leeuwenhoek

Anton von Leeuwenhoek, a Dutch merchant, was the first person to report his many discoveries after using a simple microscope. He lived a simple life and had little or no education, but his inquisitive mind led him to knowledge previously unknown to man. In his youth he worked with a fine lens in a textile mill and was fascinated by what he saw. He learned to grind his own lenses as a hobby and was rewarded for his practical use of leisure with the discovery of a tiny world never before seen by the naked eye. Through his microscopes, Leeuwenhoek saw the organization of cells. But imagine his surprise at seeing hundreds of tiny living organisms scurrying beneath his lens!

"What are they?" he asked. He wrote to the Royal Society in London. Its members were men of science who had spent many years experimenting and recording what they observed. At first they ignored his questions, but Anton persisted with his writings and questions. Finally they came to see for themselves. By this time, Anton von Leeuwenhoek had named his little creatures "animalcules" or "little animals." This name was later changed because further study proved that not all of Leeuwenhoek's animalcules were animals. Some were microscopic plants which we now call bacteria.

It was some time before a connection was made between these microorganisms and disease. Nevertheless, Anton's finding stimulated other questioning scientists and they looked forward to seeing these living organisms under their microscopes. They, too, began to ask: "What are they?" "From where did they come?" "What do they do?" It was not until the nineteenth century that Louis Pasteur was able to give satisfactory answers to some of these very important questions about disease.

Early Use of the Microscope

OBSERVE

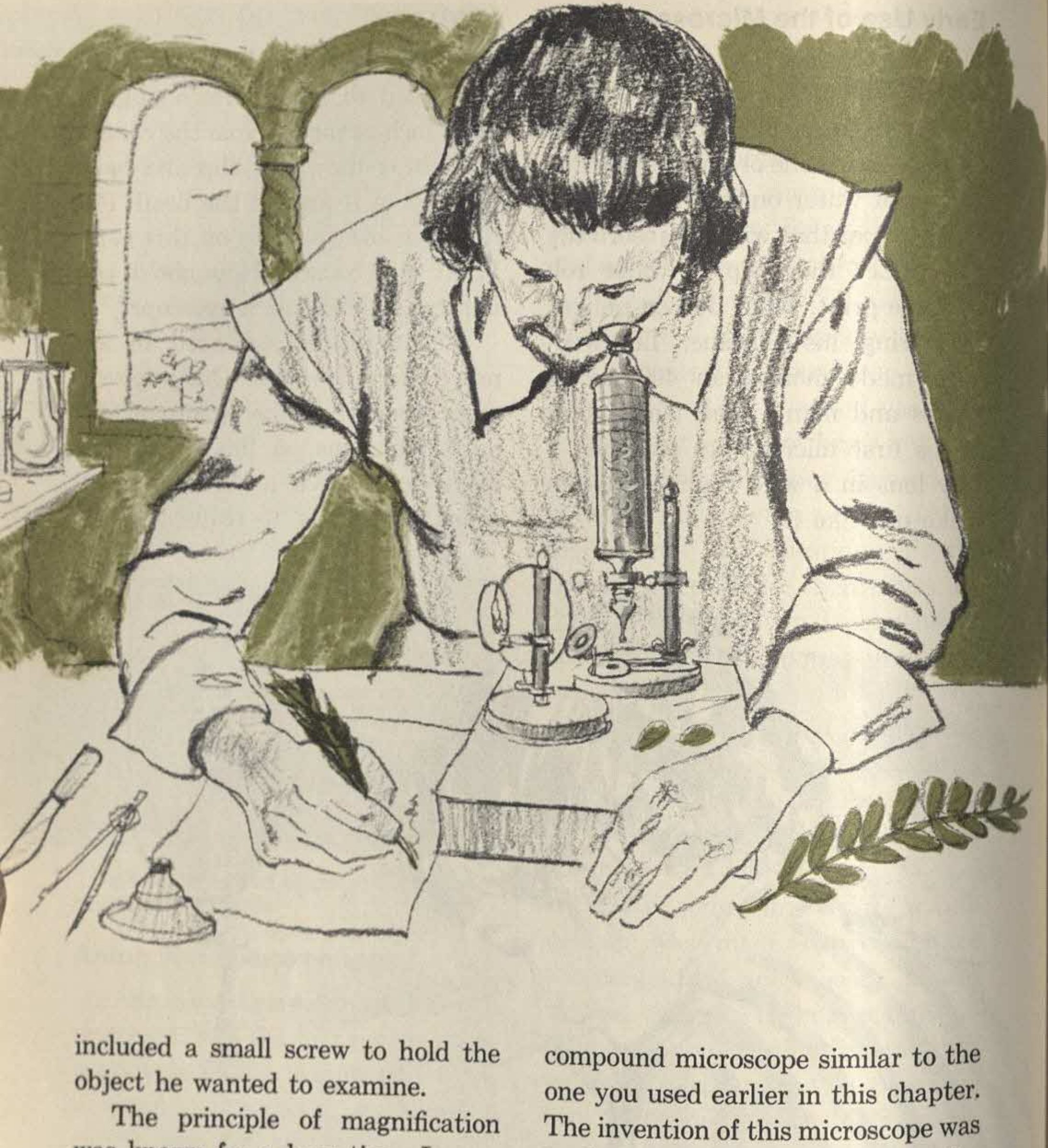
Obtain the smallest print you can find in a magazine or newspaper. Put a drop of water on it. Try to use a glossy paper that will not absorb the water. Let the drop of water roll over the print. What do you notice?

During his lifetime, Leeuwenhoek made more than 400 microscopes and many more lenses. One of his first microscopes was just a tiny lens in a wire frame. You can make one like it.

ACTIVITY

Obtain a paper clip and a clear glass bead that measures a quarter of an inch or more across the center. Straighten the paper clip and bend one end of it around the bead. Put the bead over a letter on this page. What do you see? How could you improve this simple microscope?

Leeuwenhoek continued to improve his microscopes. One improvement is shown in the picture on this page. The lens on this microscope made an object look almost 300 times as big as it really was. It



included a small screw to hold the object he wanted to examine.

The principle of magnification was known for a long time. Lenses made from rock crystals were used by ancient people thousands of years ago. Surprisingly it took centuries before anyone put this principle to practical use. In 1590, a Hollander named Zacharias Janssen made the first use of two lenses to create a compound microscope similar to the one you used earlier in this chapter. The invention of this microscope was to change the entire approach to disease. Although a number of opticians were making these new microscopes by 1625, many scientists still preferred to use the simpler lenses.

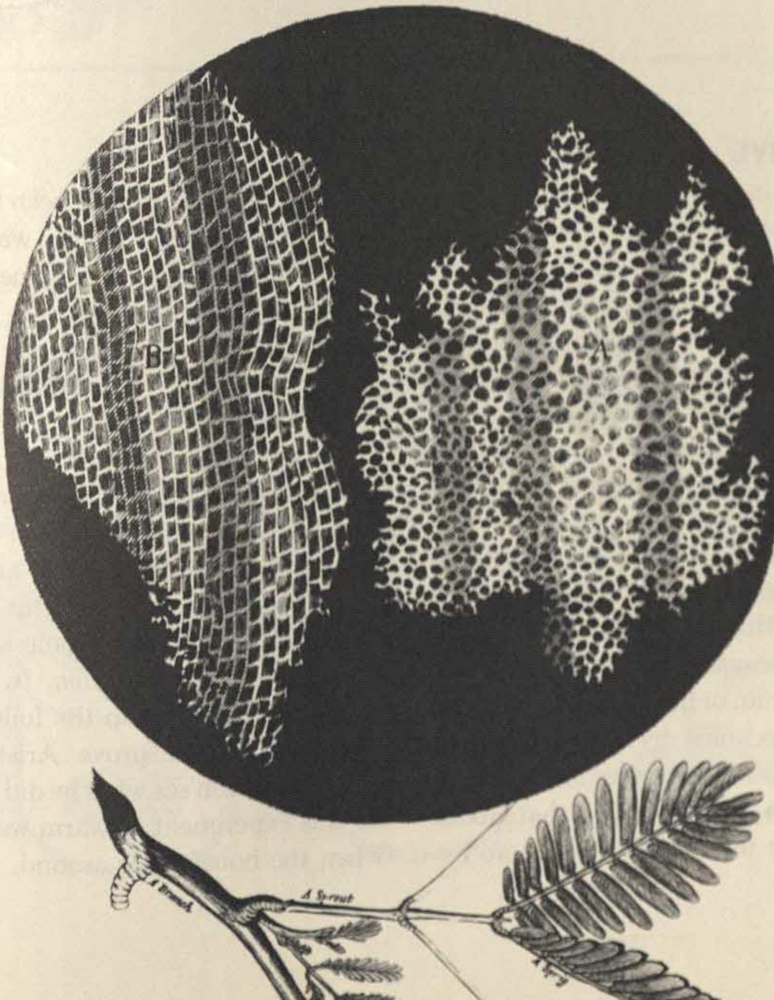
During your study of science, you will find many instances where remarkable things are often taken for

granted as was the principle of magnification. The related case of the microscope is another example. Can you think of others?

Several scientists experimented with lenses before the first microscope was perfected. Do you know to what use Roger Bacon applied his lenses? What can you find about Marcello Malpighi's microscope? Did Galileo have any ideas about a microscope? Who named the microscope?

About 50 years after Janssen's invention, Robert Hooke designed and built his own compound microscope. He used his skill as an artist to draw what he observed through his microscope. He drew the eye of a fly, the structure of feathers, and a flea very accurately. The lens of Robert Hooke's microscope also revealed the tiny divisions of a piece of cork tissue. He drew the tissue and called these smaller parts "cells." His remarkable drawings were published in 1664. Why is it important to draw what you see through a microscope?

Drawings of cork made by Robert Hooke



OBSERVE

You can repeat Robert Hooke's famous observations of cork. Your teacher will cut a very thin slice of cork for you to examine. Cork actually comes from the bark of a tree. When the slice of cork is cut thin enough to allow light to pass through, place it on a clean glass slide. Put on the cover slip and view it through a microscope.

Do you see the same box-like structures that were observed by Robert Hooke? Hooke called them cells because the structures reminded him of little rooms. The little rooms occupied by religious monks in Hooke's time were called cells. Although the cork "cells" that Hooke saw were not alive, one or more living units called cells have been found in all living things. Hooke was the first person to give the name cells to the tiny units out of which living things are made.

Francesco Redi

In about 384 B.C. Aristotle introduced the idea that living organisms come into existence from non-living matter, but neither he nor anyone else could explain how this happened. This idea has become known as *spontaneous generation.* In 1668, Francesco Redi set up the following experiment to disprove Aristotle's theory. You can see what he did if you do this experiment in warm weather when the house-fly is around.

EXPERIMENT

You will need six pieces of meat and six clean jars. Put one piece of meat in each of the six clean jars. Cover jar 1 with a piece of heavy paper or plastic. Cover jar 2 with a piece of gauze. Secure the covers to the jars with rubber bands. Let the other four jars remain open to the air for about 2-5 days.

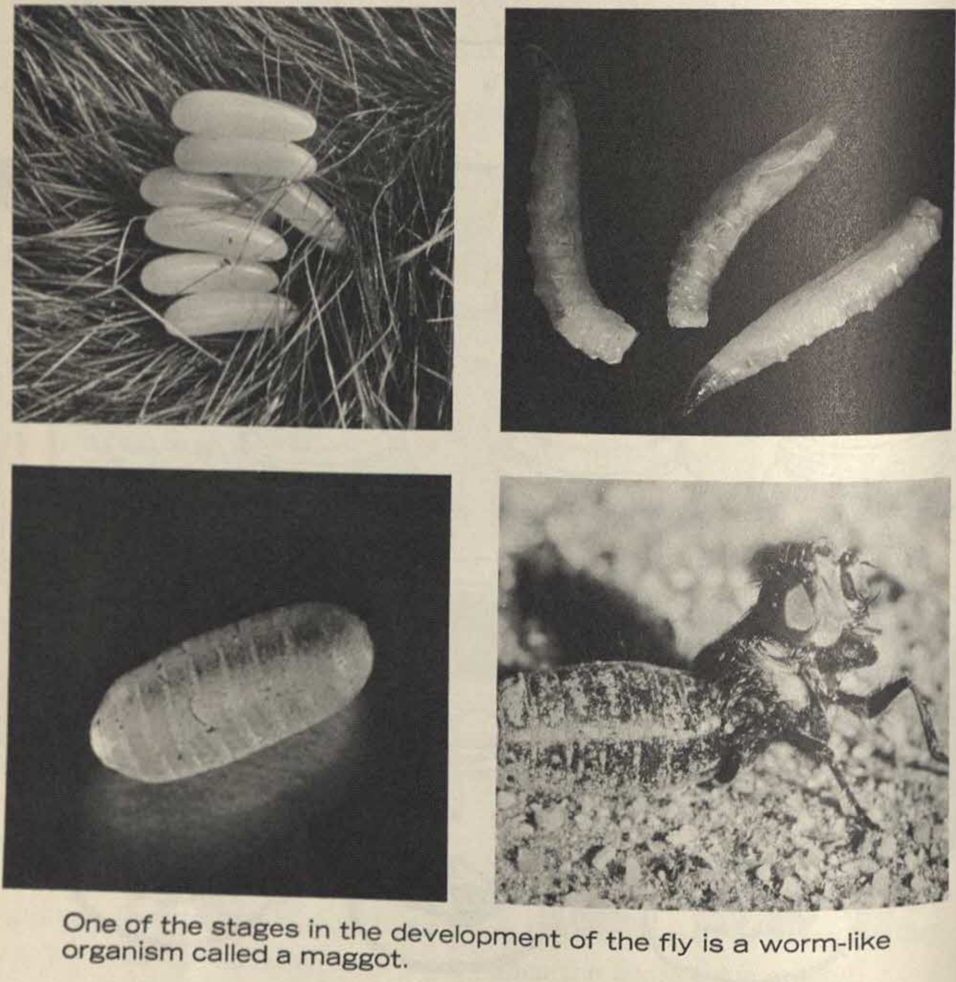
Notice how the flies are attracted to the meat. What do you think attracts them? Look for their eggs on the paper and gauze. Observe how the flies go to the meat at the bottom of the uncovered jars to lay their eggs. Watch carefully and record what happens.

Check your jars after 24 hours. Little "worms" begin to form from

the eggs. These wormlike living things are called *maggots*. In approximately 2 weeks they will develop into other flies. Have you ever seen maggots in your garbage container? Did maggots appear in the covered jars of your experiment? Why?

Why were there no maggots in jar 1? What did you observe about jar 2? Why did maggots appear only in the open jars? Did the maggots come from non-living matter? What did Francesco Redi prove with this experiment? □□

Every variety of organism reproduces its own kind. Every living creature comes from another living creature of its own kind and not from non-living matter. Some living organisms go through different stages of development during which the young do not resemble the mature adult. This is true of the fly, the mosquito, and the butterfly. Can you name any others?



One of the stages in the development of the fly is a worm-like organism called a maggot.

Edward Jenner

The spread of disease has threatened humanity from the earliest periods of history. It was for good reason that fear of the Bubonic Plague lasted for many centuries. Scarlet fever, diphtheria, and influenza have made periodic appearances as they swept across the continents of the earth.

Smallpox, a familiar danger since early times, seemed to grow more dangerous and harmful with each outbreak, until it reached its height during the eighteenth century. Many people of Europe, Asia, and Colonial America were victims of smallpox at this time. High fever and skin eruptions were the most common symptoms, but more often than not, the disease was transferred to someone else before the symptoms appeared. Anyone who lived through a mild attack of smallpox was assured of freedom from the disease, but it was not until he recovered that he could feel confident he would not die. It became a common practice to try to acquire a mild case of the disease for protection, but there was no guarantee that the attack would be a light one.

Doctor Edward Jenner successfully vaccinating James Phipps

During this period Edward Jenner was a young country doctor in England. As a youngster he heard that cowpox, a disease of cattle, and smallpox had something in common. He observed that persons who worked among cattle and became infected with cowpox did not catch smallpox. Without ever knowing what was the basic similarity between them, he began to make several tests.

From a dairymaid who had cowpox, he took just a slight amount of the infectious material from an open sore and rubbed it into the scratched skin of a young boy, James Phipps. Soon a sore, characteristic of smallpox, appeared over the place marked by Doctor Jenner. In time it dried, a scab appeared and fell off, and only a scar remained. Any attempts to produce smallpox in the boy were unsuccessful.

This was a history-making event made possible by an inquisitive doctor. With this breakthrough, smallpox began to decline. Look at your arm or leg or whatever spot was chosen for your vaccination against smallpox. The fact that you have a scar is your proof that you were once vaccinated to protect you against this disease. At times it becomes necessary to receive additional protection against smallpox. When you travel to a foreign land, or when there is danger of an epidemic, another vaccination is required.

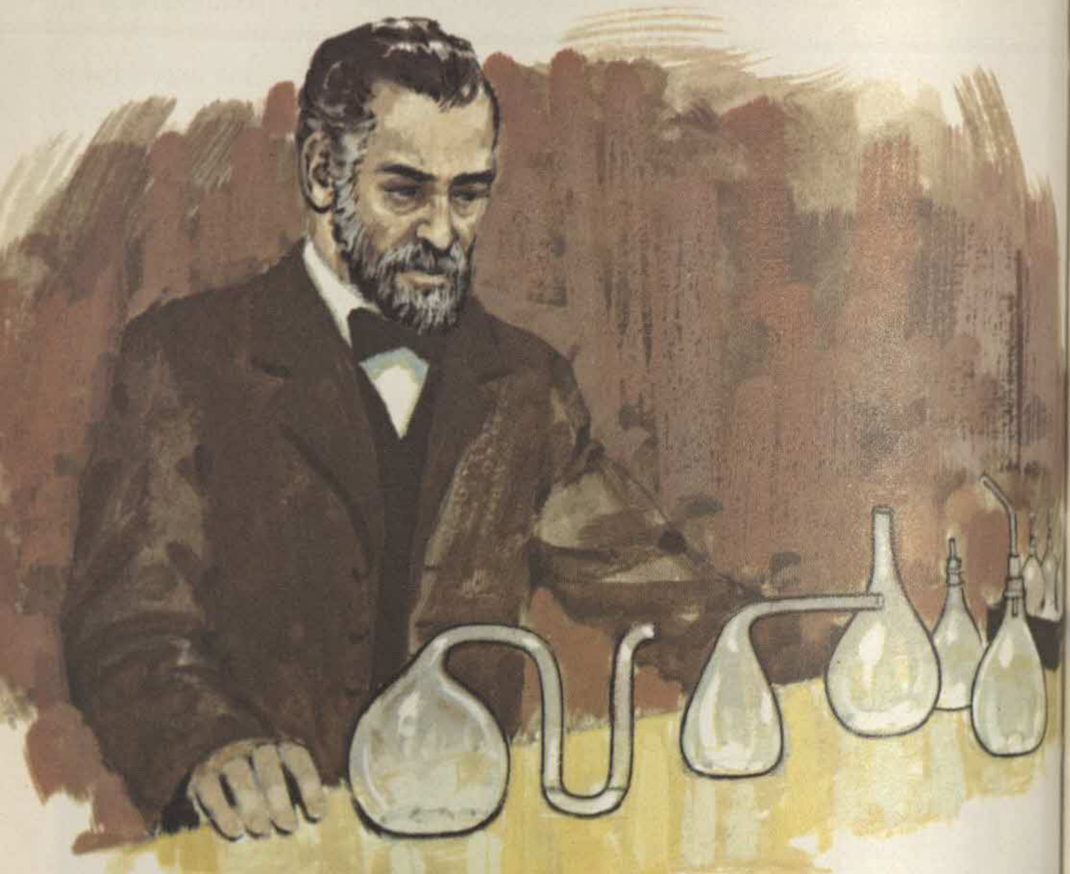
Louis Pasteur

For centuries it was known that some change took place in grape juice to turn it into wine. In 1835, scientists knew that yeasts played an important part in bringing about this change. Do you remember what this process was called? For some years French merchants were concerned because their wine was not selling. It did not taste good and often made people sick.

Louis Pasteur, a young chemist, began to study about fermentation. He thought that a better understanding of what happened during the change from grape juice to wine might help the wine industry of France to solve its problem. He had an idea! He examined different wines under his microscopes and saw that some contained various kinds of bacteria, but the good wine had only the microscopic yeasts. Pasteur kept the "healthy" wine separate from the "sick" wine.

Then he tried some experiments of his own. He took several samples of "sick" wines and heated them at different temperatures until he could find no more living bacteria when he examined them under his microscope. Pasteur found that the sample on which he used the lowest temperature necessary to kill the bacteria was safe to drink and retained its pleasant taste. Louis Pasteur was able to teach others how to produce the finest and safest wines in France. This process of heating the liquid to

Louis Pasteur



kill the harmful bacteria is called *pasteurization*. It was named after Louis Pasteur for his great contribution in combating disease.

With the discovery of the world of microorganisms, men's minds turned again to the idea of spontaneous generation. No one knew how microorganisms originated or continued to exist. Pasteur did not believe in spontaneous generation, but he was unable to answer some questions about it. He had already proved that bacteria could be killed by heat and that if the container remained closed, no other microorganisms would enter. If the same containers were open to the air, microscopic examination showed the presence of microorganisms. Could he apply Redi's principle that life comes from life? Or did microorganisms spontaneously develop from the air? He answered these important questions by performing the following experiment.

EXPERIMENT

Take three test tubes and to each add some dissolved beef bouillon. This can be made by mixing one bouillon cube with warm water and a spoonful of sugar. Into each tube place a one-hole rubber stopper. Obtain three glass tubes, each of a different shape, as shown.

Place a tube in each of the rubber stoppers. Into the S-shaped tube, put a few drops of water. Why is this done?

Heat each test tube slowly until the liquid boils. Allow the liquid to boil for ten minutes, then carefully place each tube into a rack and place it on a window sill. Observe each tube for a week. What do you see in each tube?

Repeat the experiment, only this time sterilize all of the materials used. What happens this time? How did this experiment help to disprove the theory that living things come from non-living objects?

Pasteur's Germ Theory of Disease

During his study of fermentation, it is possible that Pasteur became acquainted with the writings of Robert Boyle. Two centuries earlier, Boyle had stated that the secret of the problem of many diseases may well be found in the secrets of fermentation. Could it have been this thought that led Pasteur to study the disease called anthrax, that was taking the lives of half of the sheep in Europe? Did he link the mysterious happenings in the wine industry with the mysterious happenings in the lives of these animals?

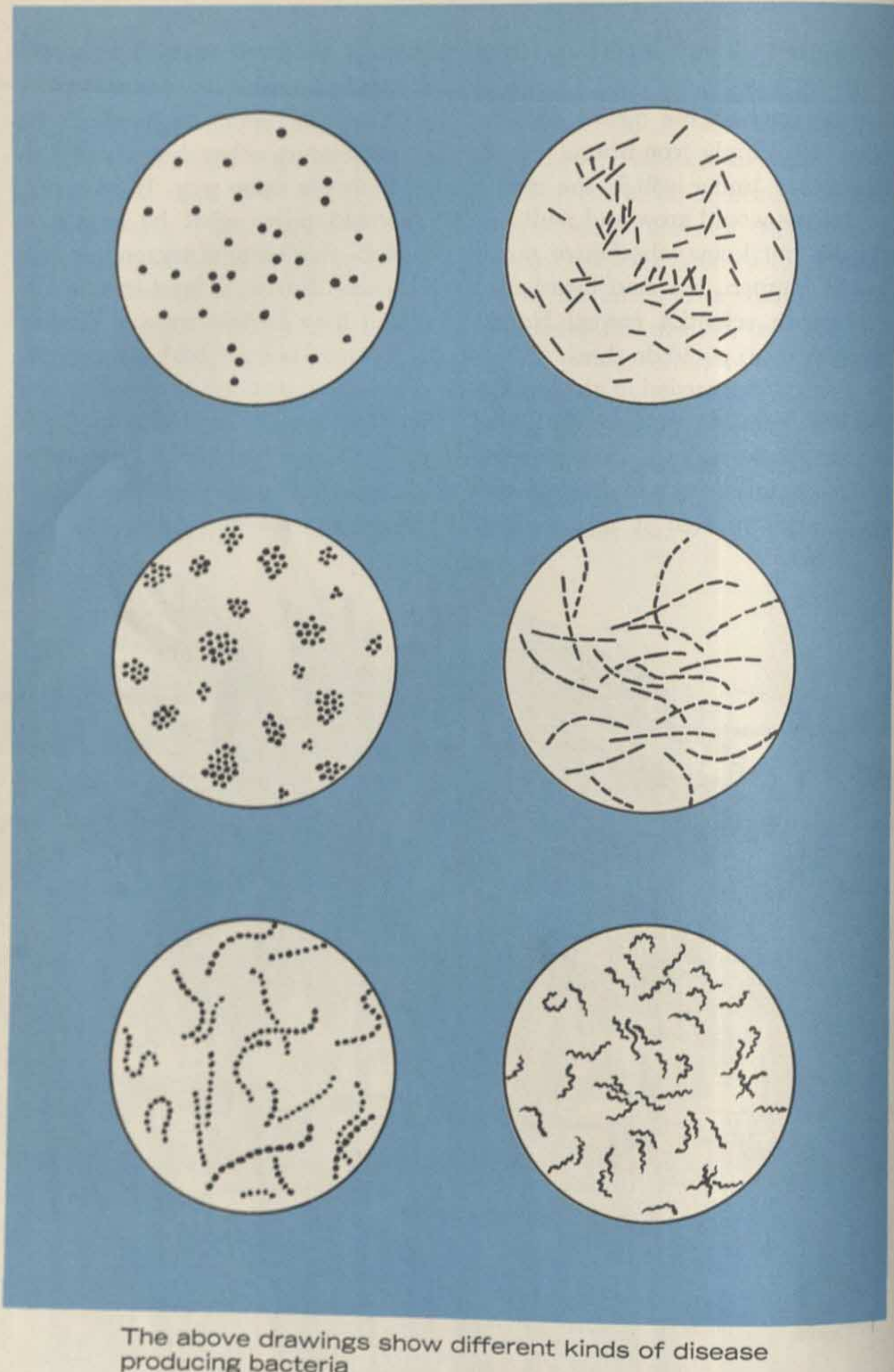
Since 1838 it was known that microscopic, rod-like structures were found in the blood of sick sheep, but their presence had not been related to the disease. Men who worked among the sheep or in wool factories contracted the disease, too. For this reason it was often referred to as "wool-sorter's disease." In both cases it was a deadly disease.

Pasteur hoped someday to prove that microorganisms are directly related to disease, if not the actual

cause. He took samples of blood from diseased sheep and tried to isolate the organism. This means that he tried to supply conditions in his laboratory under which the microorganisms would grow and multiply. He did not know whether or not it would happen, but had heard that a German scientist named Robert Koch (KOKE) could do this.

Pasteur succeeded in growing the rod-like bacteria outside the blood stream of the animal. He took some of the material from his culture medium and injected it into healthy animals. Soon the healthy sheep developed anthrax.

Pasteur then wondered if he could produce other diseases in animals in the same way. If he could, it would prove what he long suspected—that harmful microorganisms do cause disease, at least in animals. Could they be the cause of disease in human beings, too? Amazingly, one experiment led to another and Pasteur, always alert with his keen powers of observation, was convinced that microorganisms cause disease in man.

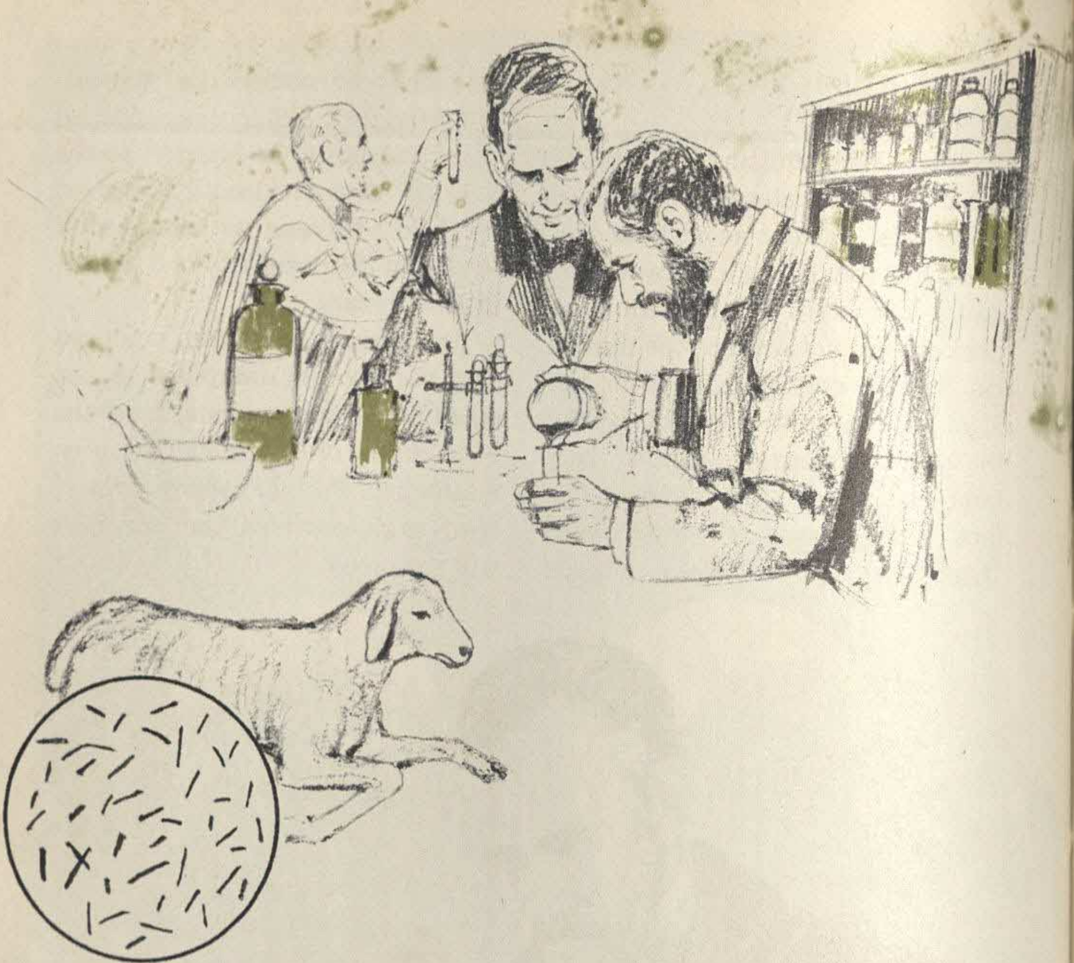


The above drawings show different kinds of disease producing bacteria

Pasteur's Principle of Immunization

While transmitting a disease called chicken cholera from one fowl to another, Pasteur accidentally injected bacteria from a culture that was a few days old. When these chickens did not acquire the disease but became only slightly ill or not ill at all, he grew suspicious. Only the hens that were given "fresh" bacteria contracted the disease. The first group were reinjected with "fresh" bacteria. Pasteur noticed that they did not develop the disease even then. When this happened again and again, he referred to the chickens that accidentally received the "old" bacteria as immune, or free, from the possibility of contracting the disease.

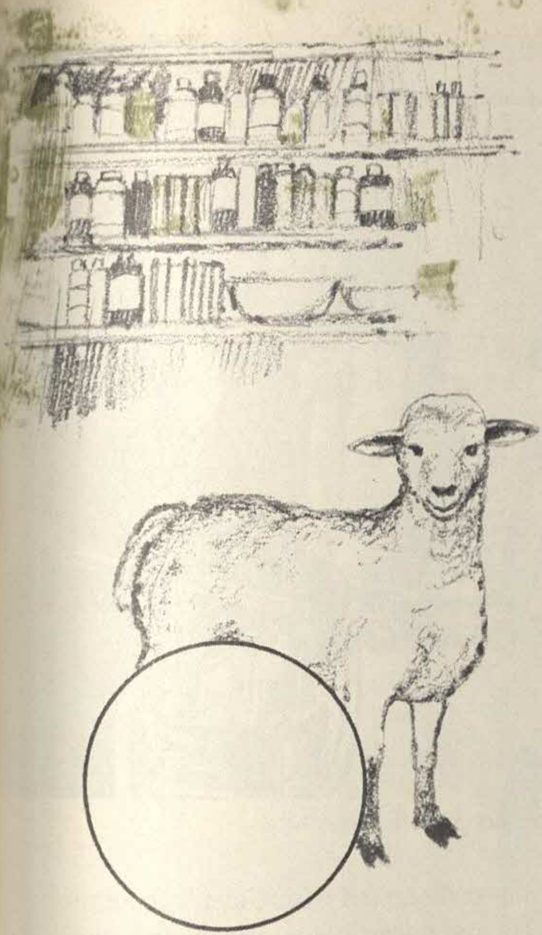
Inoculation had been practiced since the days of Edward Jenner, but scientific principles confirming the germ theory of disease had not been established. Pasteur's many years of hard work provided the principles and the proof.



To further apply this principle, Pasteur returned to the sheep. He took samples of blood containing the rod-like anthrax organisms and grew more of them in his laboratory. The blood of the animal was used as a place to grow the bacteria. When he produced enough of the bacteria, he added them to a liquid and heated it. This new mixture he called *vaccine*. Vaccine is liquid containing killed or only slightly infectious living microorganisms. The animals injected with Pasteur's vaccine did not catch the disease anthrax, and any attempt to produce this disease in them was unsuccessful.

His long suspected theory that microorganisms were producing diseases in animals was proved true. Men working with the animals were then inoculated with the vaccine and spared from acquiring anthrax. Anthrax was conquered. The "Germ Theory of Disease" was established.

Vaccine for rabies, or hydrophobia, another disease of animals (especially dogs), is an added accomplishment of Pasteur. Rabies can be transmitted to human beings by the



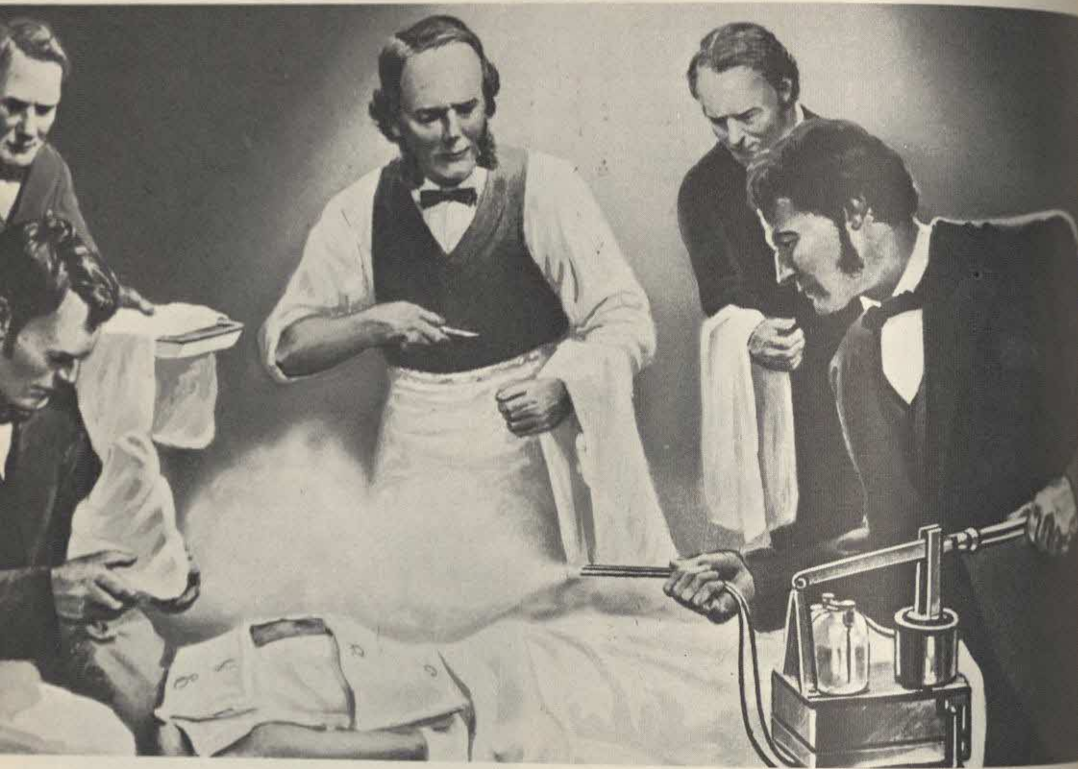
bite of an infected animal. Louis Pasteur began to immunize dogs and later extended this treatment to persons who were bitten by animals with rabies. See if you can find the story of Joseph Meister, the first human being to be inoculated for rabies.

Lister's Antiseptic Techniques

What is an infection? Did you ever have an infection? What did you do to help clear it up? *Sepsis* (SEP-sis) is another term used for "infection" caused by harmful bacteria. The prefix *anti* means "against." What does antisepsis mean? What is an antiseptic? The prefix *a* means "without." What does asepsis mean?

Joseph Lister, the conqueror of surgical sepsis, is the "Father of Antiseptic Surgery." He was the first to recognize a similarity between infection in wounds and fermentation. Pasteur had concluded that if some bacteria produce "unhealthy" wine during fermentation, undesirable bacteria could produce an unhealthy state in man. Do you recall how Pasteur proved this germ theory of disease?

Joseph Lister



How did Joseph Lister prevent the spread of infection?

Building on Pasteur's thought, Lister saw wound infection as an undesirable fermentation in man. You may recall from your experiments another process carried on by special bacteria, called putrefaction. It is similar to fermentation and is linked with infection. Putrefaction can be defined as a decay of proteins by specific bacteria. Body tissue contains protein, so this process may also occur in wounds. How do you think these bacteria are transmitted?

Lister was most grateful to Pasteur for his study of these bacterial actions and thanked Pasteur publicly whenever the opportunity arose.

Lister disagreed with Galen's theory. He and most doctors dreaded to see the "laudable pus" about which Galen wrote at great length. Because of infections, the number of deaths after surgery was very high.

Lister saw Pasteur's germ theory of disease as an answer to the problem of wound infections. He followed Pasteur's work closely and did all he could to protect wounds from microorganisms. He knew that Pasteur used heat sterilization to kill bacteria, but this could not be applied effectively to a wound. Thus Lister turned to chemicals. Could he find something that did not harm body

tissue but would still kill harmful microorganisms? After several unsuccessful attempts, *carbolic acid* finally became the antiseptic that produced the best results.

Following this discovery, measures were taken to improve the cleanliness of instruments and particular attention was given to the development of methods to prevent wounds from becoming infected. Today there are many different antiseptics made from various chemicals which help to check the growth of microorganisms. You tested antiseptics found in toothpaste in an earlier experiment. Do you remember what happened?

COMPARE

You can find out which antiseptic has the greatest effect on bacterial growth.

Obtain three sterilized Petri dishes. Expose them to the air for twenty minutes. In the center of each dish place one drop of a different antiseptic such as iodine, Merthiolate, Mercurochrome, or Bactine. Close your dishes, tape them, and place them in a warm place. Observe them after three days, four days, five days.

Do you notice any differences? Which has the largest area free of bacteria? Why do you wash a cut and add some antiseptic to it?

Modern Surgery

Strong chemicals are no longer necessary to keep surgical wounds free from microorganisms. Aseptic technique has now replaced the old method. Everything is done to keep whatever comes into contact with a wound as free from microorganisms as possible. Instruments and materials used by the doctor during an operation and dressings used to cover the wound afterwards are sterilized in a large oven-like apparatus called an *autoclave* (AW-toh-klayv). Steam under pressure in the autoclave produces such great heat that no microorganisms survive. This is what we mean by preventive measure against infection. No other technique is necessary if microorganisms are kept from the wound.

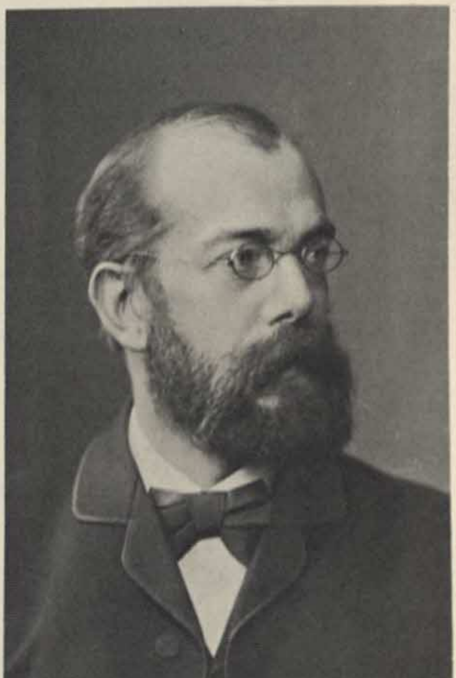
Aseptic practice used in modern surgery is an outgrowth of the chemical antiseptic technique begun by Lister.

How are these doctors guarding against the spread of infection?

Robert Koch

Robert Koch (KOKE), in Germany, worked hard to grow different organisms and link them with specific diseases. Using his own findings and the findings of the earlier scientists, he arranged his ideas into "Koch's Postulates," as they are known today. According to Koch, a particular microorganism can be linked to a specific disease, under the following conditions:

1. if it can be found on or in the living thing having the disease;
2. if it is capable of being grown outside the body;
3. if, on being injected into a healthy animal, the disease is reproduced and the microorganism found in the animal can be grown again.



Robert Koch

Working successfully according to these ideas, the anthrax germ and the tuberculosis germ were isolated and recognized by Koch as the specific organisms linked to anthrax and tuberculosis diseases.

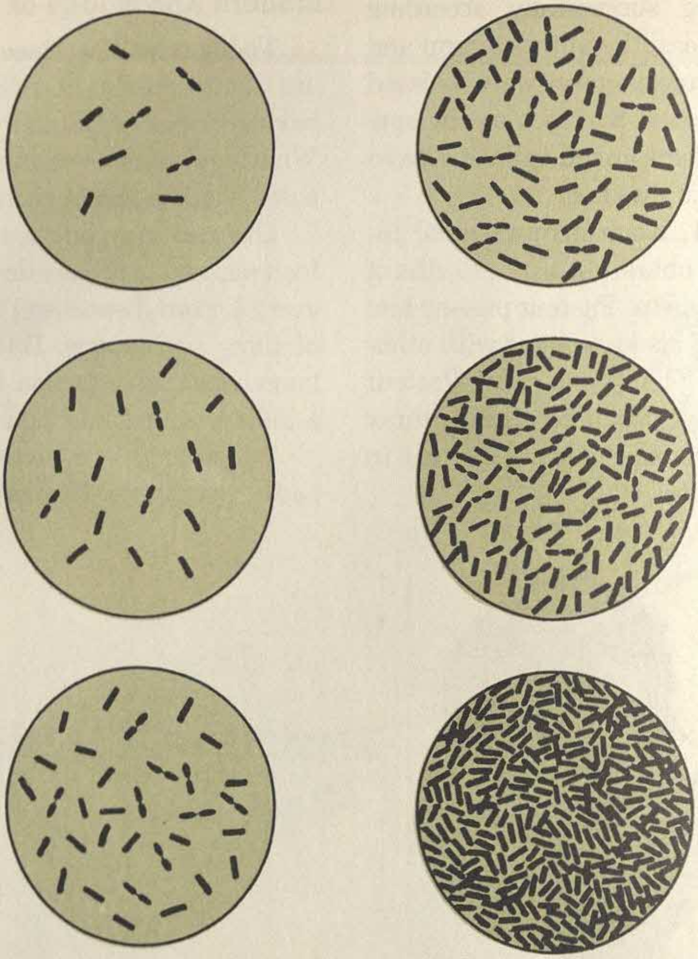
In 1881, Koch demonstrated his method of obtaining pure growths of microorganisms. Pasteur praised him for sharing his knowledge with other scientists. That same year, Pasteur successfully produced the anthrax vaccine by using Koch's method to grow bacteria.

Modern Knowledge of Disease

Today scientists know that there are many kinds of disease, each having its own signs and symptoms. What are some symptoms of disease? Make a list of them.

Diseases may be classified as infectious and non-infectious. Almost every known disease will fit into one of these two groups. Do you really know what an infection is? Why is a disease called infectious?

Infection is the invasion of the body by harmful microorganisms



that begin to attack healthy cells. In this manner, they are capable of starting infectious disease. You might understand this action better if you think of it as a battle going on where the infection is located.

Some microscopic organisms reproduce themselves by splitting in half. Bacteria, for example, reproduce in this way. One organism that enters the body will, under favorable conditions, soon become 2, and these 2 will divide until they are 4, 8, 16, and 32. They continue to divide until an "army" of microorganisms is present in the body. If permitted to continue, the bacteria cause damage to cells and tissues where the "fighting" is going on.

There are several forces "opposing" bacteria. These forces try to "defend" your body. It is because of the body's defenses that you are not ill more often.

An infectious disease that can be transmitted to another human being is called a *communicable* (kah-MYOO-nih-kah-b'l) infectious disease. Not all infectious diseases are communicable. Tetanus, or lockjaw, is a noncommunicable infectious disease. It is caused by a microorganism that enters the body through a wound or opening in the skin.

Contamination (kahn-tam-ih-NAY-shun) is a term frequently used in relation to disease. A person or object exposed to disease-producing organisms is said to be *contaminated*. A bandage from an infected wound or foods that have fallen on the floor are examples of contamination. Visiting someone who has measles, mumps, or chickenpox is an easy way

to overexpose yourself to contaminated objects. Because of contamination you should never eat or put into the mouth anything that is not clean. Are pencils and erasers contaminated? Is it wise to chew your fingernails? Do you have the good habit of keeping your hands and objects away from your face? Do you remember from your experiments how fruits and vegetables become contaminated?

It is sometimes possible to spread disease while not contracting it yourself. When this happens the person is called a *carrier*. The carrier can only spread the infectious, or germ-spread, diseases.

Any disease not caused by invading microorganisms is called *non-infectious*. A non-infectious disease may be due to abnormal growth of cells as in cancer. Or it may be caused by an organ that cannot function or does not function well, as in diabetes. Have you ever heard of diabetes? Do you know anyone who has this disease? Try to learn more about this disease. What can you find out about the diet of a diabetic? What other non-infectious diseases can you name?

How Microorganisms Enter the Body

What are the most common ways that microorganisms can enter your body? Have you any control over what enters and what does not? Do you have more control over what goes into your mouth than what enters through your nose? How are harmful microorganisms most likely to gain entrance to your body?

Microorganisms exist all around you. They are even in the atmosphere along with waste gases, dust, pollen, and other impurities. What are some of the conditions which germs do not always find in the atmosphere that are necessary for their growth? How do the microorganisms in the air enter your body?

Like all other living creatures, microorganisms fight for survival. This is where you become very important to them. How many times have *you* provided the requirements necessary for their growth? How did you invite them to a party at your expense? Think twice hereafter before you put that pencil, paper clip, or finger into your mouth. Remember that one particle of dust can carry such tiny organisms to a new

Why must we cover our coughs and sneezes?

environment — your body — where the very best conditions will be assured. A week or so of illness might be your reward for granting this favor.

Air-Borne Microorganisms

Air can become contaminated easily, but fortunately most microorganisms are not harmful. A person infected with a disease of the respiratory system exhales numerous infectious organisms. Coughing or sneezing greatly contaminates the nearby atmosphere. Have you ever seen a spray of moisture caused by a sneeze? "Droplet infection" is the term used to describe infection spread in this manner. A thoughtful individual will always attempt to delay violent sneezing by pressing the index finger against the separation between the nostrils. This usually checks the sneeze long enough to let you reach for a handkerchief. When the mouth is uncovered while coughing or sneezing, the organisms may be spread 10 to 15 feet!

Most air-borne diseases are spread by droplet infection. Bacteria and viruses contaminate the air in this way. Measles, mumps, scarlet fever, diphtheria, tuberculosis, and the common cold are some of the diseases transmitted by droplet infection. The tuberculosis germ is frequently found in saliva, but it can survive for some time without moisture. Why is spitting a very bad habit?

Diseases that produce skin eruptions in which the infectious organ-

ism is lodged, also contribute to air-borne infections. The disease may be spread when the skin dries and falls off. Such diseases are often caught by *direct contact* with the infected person or indirectly by using things he had been touching. Smallpox and chickenpox are diseases transmitted in this way.

Since men must breathe to maintain life, the possibility of acquiring or transmitting air-borne diseases is very real. Whether or not the individual is able to resist the disease depends on many things. Natural control methods are available but often neglected. Crowded places and sick rooms should be well ventilated. Better use of the purifying effect of the sun tends to decrease the spread of disease. Blankets, clothes, and bedrooms should be exposed to air and sunlight as much as possible. The simplest antiseptic solution—soap and water— lessens the chance of infection.

EXAMINE

Cover one side of a clean glass slide with Vaseline. Place the slide in the open air overnight, then examine the slide with a magnifying glass or under your microscope. What do you see?

Mark a one-inch square on the Vaseline. How many dust particles are there in the square? Would you find more dust in other places? Use other slides to check for dust particles in different locations.

Insect Carriers

Some insects are common carriers of disease. They accomplish this task in one of two ways. Insects, such as the house-fly, carry harmful microorganisms that have become attached to their bodies from the air. The organisms are then deposited on food, in water, or on other objects used by an individual. In this way these common things become a source of contamination from which a person might contract disease. Insects also transmit disease by biting the person. Insect bites are not uncommon. Fortunately, most are not disease-producing. They cause a slight irritation in the area of the bite and usually clear up quickly. What are some more serious infectious diseases contracted from insect bites?

How does this insect help spread disease?

Water-Borne Microorganisms

Intestinal diseases caused by harmful organisms in contaminated water seldom occur any more in the United States. Efforts of public health authorities have greatly decreased this possibility. Water used for public drinking purposes is examined frequently by men who are especially trained to know its degree of safety. Because the best conditions for bacterial growth are not usually found in purified water, harmful organisms cannot live for long in this environment. Once taken into the body, however, all conditions are fulfilled. If undetected, harmful water-borne organisms may fatally infect individuals and could cause an epidemic.

In 1854 an epidemic of a disease called *cholera* (KHOL-ur-uh) in London was caused by the seepage of sewage into a drinking well. In 1892 another epidemic of the same disease occurred in Hamburg, Germany, due to contamination of the public water supply. This particular epidemic took the lives of almost 10,000 people. A near-by town that used a sand filter to purify water from the same source was spared the dread disease. This was only one instance where the purification of water proved effective. It was not long before other cities and towns adopted similar methods. Many communities require wells and cesspools to be set a good distance apart on a person's property. Do you know why?

INVESTIGATE

Stir some dirt into a glass of water. How does it look? Would you like to drink it? Why?

Take a quart-size plastic bottle with a screw top. Cut off the bottom. Make a small hole in the screw top. Fasten a plastic straw in the hole with modeling clay. Turn the bottle upside down and pour some water into it. Be sure that the water pours from the straw. Use modeling clay to stop any leaks.

Carefully wash and dry a large glass jar. Dry the plastic bottle and put it neck down into the mouth of the jar.

Take some pebbles, some coarse and fine sand, and some wood charcoal. Wash the pebbles and sand well. Rinse them in clear water.

Put a two-inch layer of clean pebbles into the plastic bottle. Next, add a layer of coarse sand and a thicker layer of fine sand. Grind some charcoal with water to make a paste. Put a half-inch layer of charcoal paste over the sand. You have now made a water filter.

Pour your glass of muddy water through the filter. How does the water look when it reaches the bottom? Do you think it would be safe to drink the water now? □□

When rain water is filtered through many feet of earth, it is partially purified in a similar way. Why are deep wells safer to drink from than shallow wells?

Epidemics caused by water-borne organisms are rare in the United States today, except in places that have not established proper measures for water purification and sewage disposal. Control of water-borne disease is accomplished when our knowledge of microorganisms is used to improve sanitation. See what you can find about the different methods used to purify water. Where is your source of water supply located? Write for information concerning methods used to purify your water. How is chlorine helpful in this process?

Discuss how transmission of infectious disease might occur with improper use of drinking fountains and by drinking from a water glass used by others.

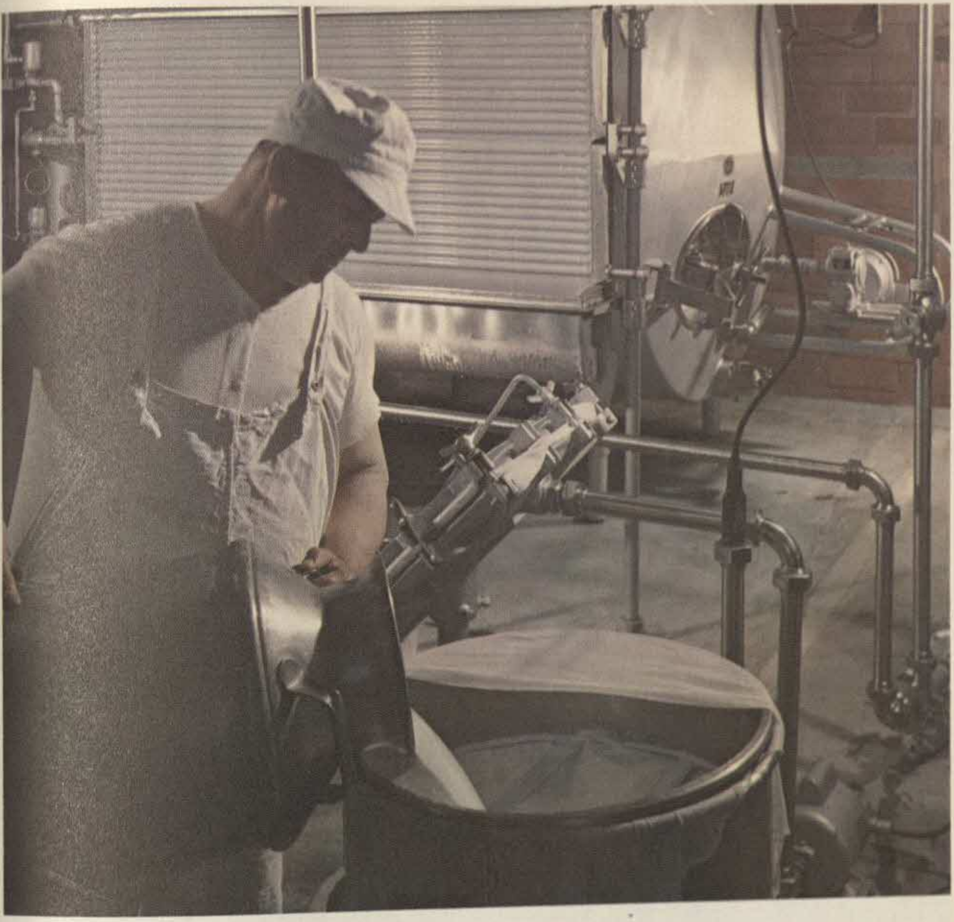
What things can you do to help keep our water supply clean and safe?

Milk and Disease

The carbohydrates, protein, and fat content of milk make it one of the most favorable substances for growth of bacteria. For this reason every precaution is taken to avoid contamination of milk from the time it leaves the cow until it reaches the user. Both harmful and harmless microorganisms grow very well in milk.

Tuberculosis contracted by cows may be transmitted to milk obtained from an infected cow. In this case, the tuberculosis germs transmitted through the milk are different from the tuberculosis germs that infect the lungs of human beings. Cattle tuberculosis was formerly contracted by infants and children, but in recent years the strict regulations of public health authorities make it almost extinct. By the frequent inspection of cattle, infected cows are discovered early and they are removed from the herd.

Why is it important to keep cows in clean surroundings?



Dairy employees are another possible source of contamination of milk. Cleanliness is very necessary in those who prepare milk for general use. What harm might come to users if one dairyman handles milk with soiled hands? How might disease be transmitted if a milk handler has a very bad cold? How does pasteurization of milk help to eliminate this problem? When is milk pasteurized? See if you can arrange a visit to a local dairy to watch milk being pasteurized.

Food and Disease

Some infections are caused by food that is not cooked properly. Thorough cooking is required to avoid upset stomach, indigestion, and diarrhea which are symptoms of this condition.

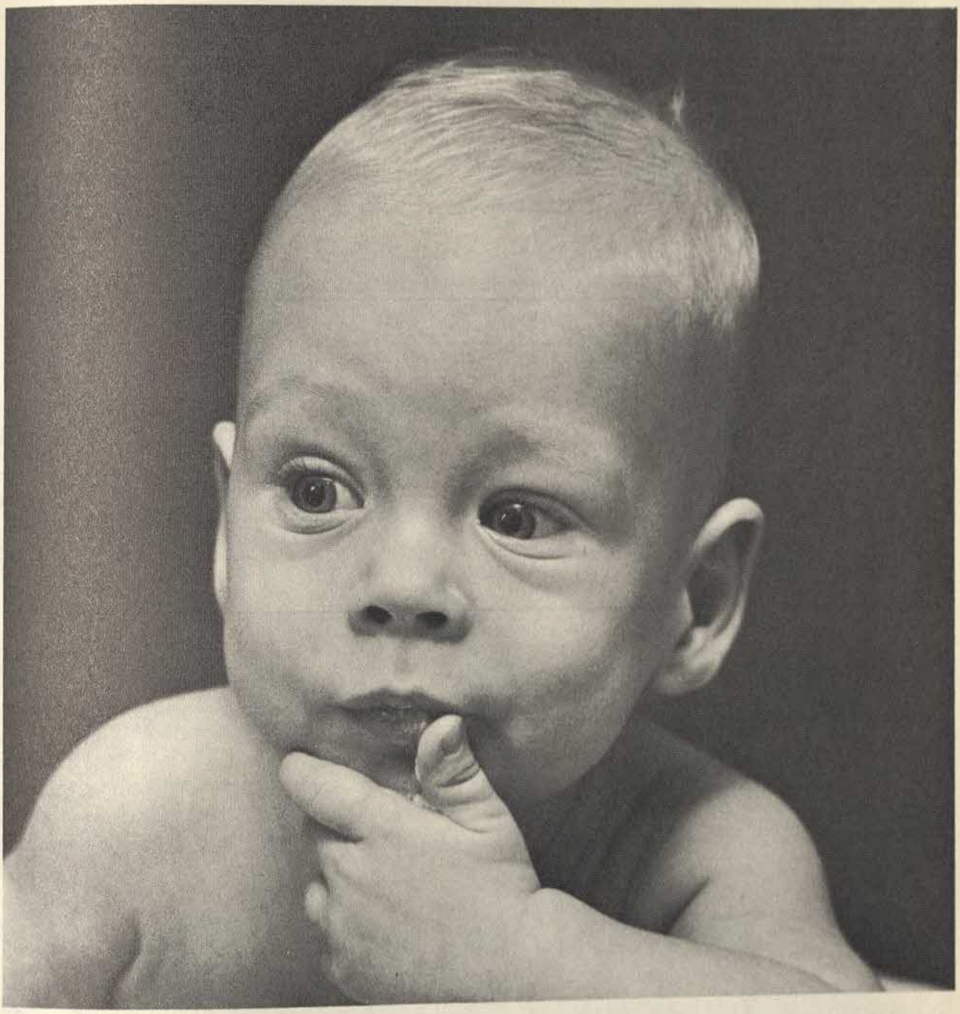
Flies and other insect carriers should be kept from the house by proper screening in order to eliminate the transfer of disease germs from the insects' bodies to the food being prepared. Make a list of insect carriers of disease.

All food demands cleanliness and special care from the time it is purchased from the grocer to its preparation in the kitchen and use at the table.

Personal cleanliness on the part of food handlers, such as cooks and bakers, is absolutely necessary. Most infections transmitted through food begin with contaminated hands. Persons with skin infections or colds should never be permitted near food intended for others.

Public health authorities in the United States take every precaution to avoid transmission of disease through food. Frequent inspections of slaughter houses and special processing of meat have decreased the chance of finding spoiled meat on the market. Similar inspections occur in bakeries. Strict attention is given to the manner of preparation and care of equipment. Improvements in commercially prepared foods—methods of refrigeration and packaging, for example—are another help in prevention of food contamination. Occasionally food poisoning still occurs. In many cases, it is found to originate in home canning done with inadequate facilities or unsanitary conditions. Once in a while, especially during warm weather, spoiled or tainted food is eaten, causing serious illness. How did people preserve food before the development of modern methods?

How are these food handlers guarding against the spread of infection?



In ancient Greece, the life expectancy of the average person was less than twenty-five years. This meant, on the average, people died at an early age. Thousands of children died in infancy! Although there were old people in those days too, a person who lived much beyond twenty-five years was considered lucky. Through the years, the average life expectancy has increased considerably. Do you know why this is so? Today each child born has every reason to expect to live about 70 years. The reasons for this are many and extremely complex, but it is agreed by most people that the growth of medical science, an understanding of disease, and the elimination of superstition and ignorance have much to do with our increased life span.

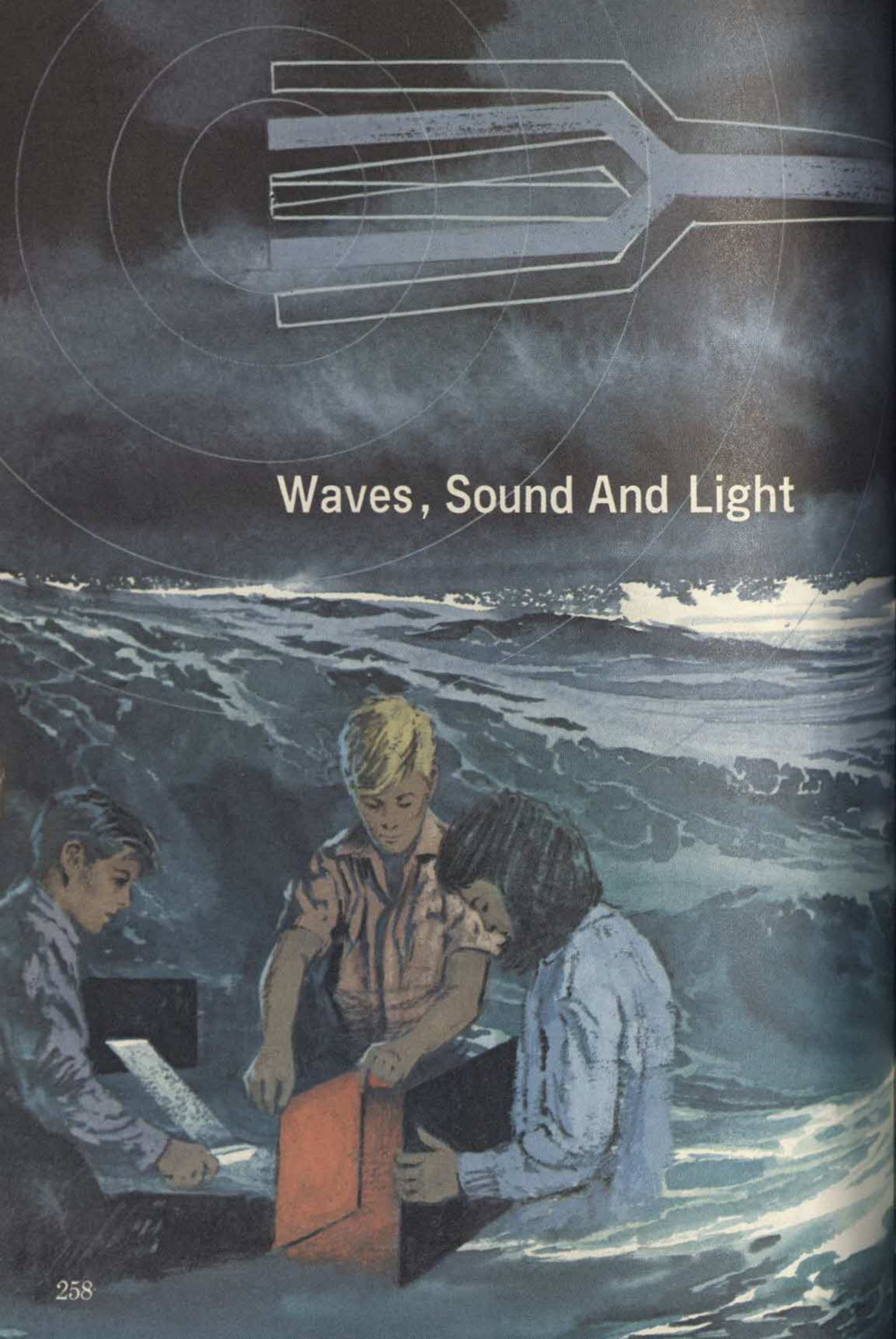
THINK

1. If all of the microorganisms in the world were to suddenly disappear, how would that affect man?
2. Why were diseases much more widespread one hundred years ago?
3. If you were a senator or congressman, serving on a health committee, what steps would you take to insure better health for the citizens of our country?
4. Why are there nations whose people still die (on the average) very early in life?
5. Why was Hippocrates called The Father of Medicine?

PROJECT

Obtain various things upon which molds can grow. You might use bread, orange peels, old cloth, leather, old fruit, or nuts. Place the things you have chosen in containers or jars. Keep records of all the conditions under which the molds begin to grow. Record the time, place, temperature, and moisture, the amount of light each object received. When the molds have grown for a time, try changing the conditions one by one. Record any new observations that you make. Remember, keep careful records; and if your teacher selects you, make a report to the class.

Waves, Sound And Light

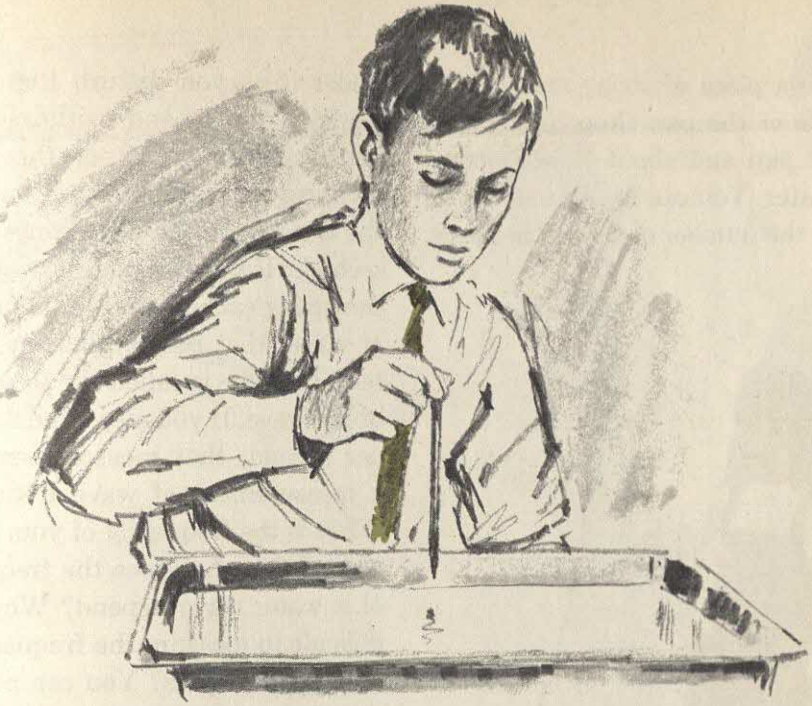


Exploring Waves

Have you ever thrown a stone into a still pond?

Have you ever watched the ripples of water spread out and disappear?

Would it surprise you to know that disturbing water in this way is closely related to sound, light, radio, and even earthquakes? The things you can learn from water waves can be applied to measuring the distance from here to the moon or tracking an orbiting space capsule. A knowledge of waves is very important today. It may very well be that waves of a different kind are closely related to every material object in the universe. It may turn out that all explanations of matter and energy will depend on a thorough understanding of waves. You can begin your study of waves by creating a small body of still water in your home or classroom, and then gently disturbing the water.



OBSERVE

Obtain a large shallow pan or pail and fill it with water almost, but not quite, to the top.

Allow the water to remain undisturbed for a few minutes until it is very still. Now with the tip of a pencil, gently touch the water in the center of the pan. Quickly withdraw the pencil and carefully observe everything you see. How do the waves move? What happens to each wave as it strikes the sides of the pan?

Repeat this activity, only this time touch and withdraw the pencil several times at regular intervals. What do you observe? Are the waves reflected at the same intervals? How do the waves differ from those made by touching the water only once?

Touch and withdraw the pencil as quickly as you can. What happens this time?

You may have to make some of your observations of the moving water by lowering your head. Are you able to see a highest region on the water wave? This part of a water wave is called the *crest* of the wave. Can you see a lowest region in the water wave? The lowest point of a wave is called the trough (TRAWF). What must you do to the water in order to make the crest higher? Does the trough get deeper when the crest gets higher? The distance between the still water level and the highest or lowest point is called the *amplitude* of the wave. How is the amplitude of the wave related to the disturbance that causes the wave?

Tie a piece of string around the outside of the pan close to one end of the pan and about 1 inch above the water. You can use this string to count the number of waves that pass under it as you disturb the water. Rapidly touch and withdraw the pencil into and out of the water in a regular fashion. Try touching the water with the pencil once every second. How many waves pass under the string each second? The number of waves that pass a place in an interval of time is called the *frequency* of the wave. If you measured 2 waves per second, that measurement was a measurement of wave frequency. What is the frequency of your water waves? On what does the frequency of a water wave depend? Why is it difficult to measure the frequency of your water waves? You can observe the characteristics of waves in another way.

The Characteristics of Energy Waves

OBSERVE

Fasten a piece of clothesline, about 20 feet long, to a doorknob, a tree, a water pipe, or some other stationary object. Hold the end of the rope in your hand so that the rope is almost level with the floor. Move your hand up and down slowly, then rapidly. What do you see? Move your hand from side to side slowly, then rapidly. What do you observe happening to the rope this time? You may recall that work is done when a force moves matter. Do you think you are doing any work as you produce rope waves?

Wave Amplitude

Energy and work are very closely related. Actually, energy can be thought of as the ability to do work.

Do rope waves have energy?

ACTIVITY

Use the same rope fastened in the same way as in the previous activity. This time, fold a heavy piece of cardboard into a V-shape and put it onto the rope as shown. Now move the rope up and down to generate a series of waves. What happens to the cardboard as the waves pass under it? Can you get the waves to travel along the rope without the cardboard falling off? How do these waves compare with the waves you made in water? Can you locate the crests of the rope wave?

Where are the troughs? How would you measure the frequency of waves traveling along a rope? What do you suppose makes the frequency vary? What must you do to the rope to make the amplitude of the waves greater? You can make several important measurements on your rope waves. Use a ruler to measure the amplitude. Which waves have the most energy?

Wave Frequency

The frequency of a wave has to do with the number of waves produced in a certain amount of time. For example, if 20 waves travel through any part of the rope in a minute, the frequency is 20 waves per minute.

MEASURE

Fasten the rope again. This time, use a watch with a second hand and carefully count the number of waves that can be produced in a minute. Work with one of your classmates. First, let him determine the frequency of the waves that you are producing, and then you do the same for his waves. How many waves per minute do each of you produce? Can you vary the frequency of your waves? Check the frequency at different points on the rope. Is the frequency the same at the tied end of the rope as it is at the other end? Is the frequency the same all along the rope? Make up an activity to find out. You might need the help of your classmates.

Wavelength

Two ways of describing an energy wave are amplitude and frequency. Another measurable characteristic of waves is their length. A *wavelength* is defined as the distance between corresponding points on waves that are next to each other. It is possible to measure wavelength by measuring the distance from crest to crest or from trough to trough.

ACTIVITY

Can you determine the wavelength of waves that you produce in a 20-foot piece of clothesline? Try marking a scale on the blackboard. Draw long vertical lines every 6 inches to serve as a background for the moving rope waves. Working with a classmate, approximate the length of waves moving through the piece of rope. Why is this difficult to do? If a Polaroid camera is available, snap a photograph of the rope, with waves moving through it, in front of the scale that you have drawn on the blackboard. Wavelengths can now be fairly accurately determined by looking at the photograph. Make sure to snap the picture at a fast enough shutter speed to "stop" the action. Under what conditions does the wavelength change?

Wave Velocity

If you disturb the rope carefully and only once, you may be able to get a single disturbance to travel the length of the rope. Is this disturbance a complete wave? Does it seem to move very quickly down the rope? To be very exact about this motion and the motion of all waves, it is necessary to measure the speed and sometimes the velocity of the waves. Speed and velocity are very similar words but they are not identical. Speed is the word we use when we refer to the distance an object or wave moves in a definite amount of time. For example, an automobile can move at a rate of 50 miles per hour. This description of an object (automobile) moving a certain distance (50 miles) in a unit of time (hour) represents the idea of speed. The units and objects can change, but the idea of speed is the same. A wave can travel with a speed of 12 inches per second. A rocket can travel with a speed of 18,000 miles per hour. There are many thousands of different speeds.

If we wish to be more exact in our description of speed we may use the term *velocity*. Velocity means speed and direction. If a car is moving northward at 50 miles per hour we say its velocity is "50 miles per hour to the north." If a disturbance is moving down our rope at a speed of 10 feet per second, then the velocity would be given as "10 feet per second, down the rope."

ACTIVITY

Using a piece of clothesline 50 to 100 feet long and a stop watch, determine the velocity of a single wave as it travels from your hand through the rope to the place where it is tied. Keep careful records of your determinations as you work along with one of your classmates. Do you think that the amplitude of a wave will affect its velocity? Produce high or low amplitude waves. What do you notice about their velocities? Produce different frequencies of waves in the clothesline. What do you notice about their velocities? Compare your findings with those of your classmates. Is there general agreement? What general statement can you make about the velocity of rope waves? Did you predict this before you did the activity?

MEASURE

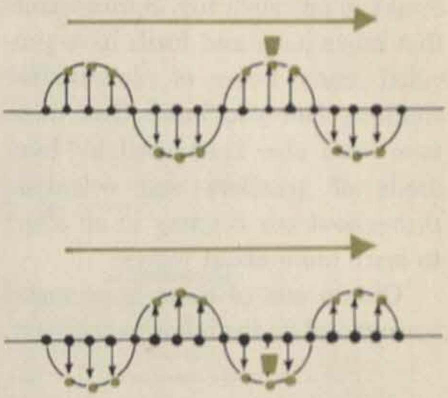
You can measure the velocity of rope waves. Using a piece of clothesline 50 to 100 feet long and a stop watch, determine the velocity of a single wave as it travels from your hand through the rope to the place where it is tied. Why must you measure the rope at some time during this activity? When you disturb the rope so that several waves travel the length of the rope, do they all travel with the same velocity?

Keep careful records as you work along with one of your classmates. What effect has a change in amplitude on the velocity of the wave? How does changing the frequency of the wave affect the velocity? Compare your findings with those of your classmates. Were some of your results different? Why? Were some of your results the same?

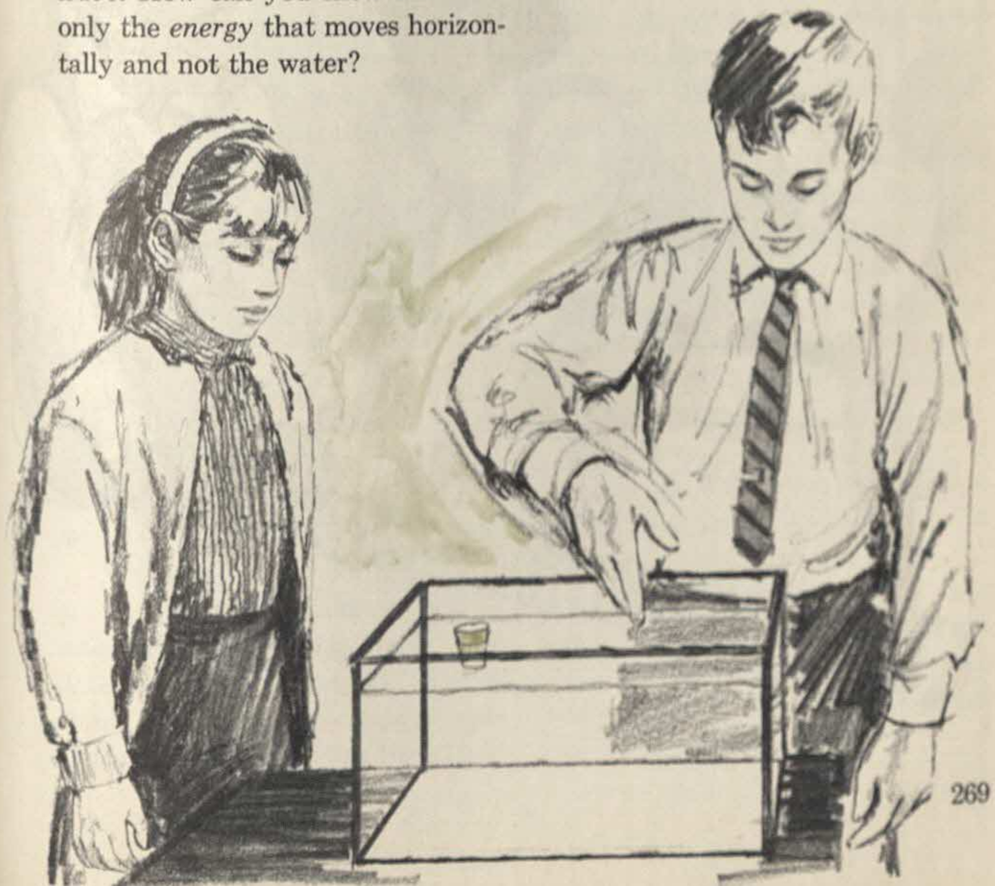
What general statements can you make about the velocity of waves in rope?

OBSERVE

Float a small cork on water in an aquarium tank or a sink. Produce waves in the water and carefully observe the movements of the cork. How does the cork behave when waves are produced? In what way does it move? What does this show you about the substance through which a wave is passing? Does the water move from one end of the tank to the other with the wave? How can you be sure? □□



When a motion is up and down and the disturbance wave it produces travels horizontally, the angle between the two is a *right angle (90°)*. Such a wave is called a *transverse wave*. How can you show that it is only the *energy* that moves horizontally and not the water?



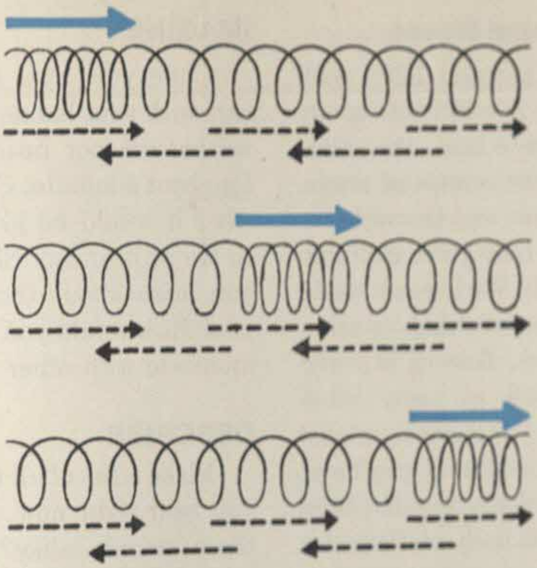
A Different Kind of Wave

Long metal springs have been sold as toys for quite some time. Slinky is one such toy. Springy coils that move back and forth have provided many hours of pleasure for children. Did you know that these toys have also been used by hundreds of teachers and scientists throughout our country in an effort to learn more about waves?

Obtain one of these large metal springs and do the following activity.

OBSERVE

Fasten the coiled spring to the leg of a desk or chair and stretch the spring along the floor. Now, using a stop watch to measure the length of time it takes, send a disturbance along the spring. You can do this in a number of ways. Hold the slinky in one hand as you stretch it across the floor; with your other hand, gather 5-10 coils until they are tightly compressed. Press the stop watch the moment you release the



coils. When the disturbance reaches the other end of the spring, stop the watch and record the time. How far did the disturbance travel? How long did the journey take? What was the velocity of the disturbance? Is the disturbance a wave? How do you know? Do the slinky coils move at right angles to the disturbance that travels down the length of the spring? How would you describe this motion?

When the direction of motion of the disturbance is *parallel* to the back and forth motion that causes it, the wave is called a *longitudinal wave.*

Now send a number of disturbances down the spring at regular intervals of time. How would you determine their frequency? Try to think of a way to calculate the velocity of the waves. How would you measure the distance from one wave to the next? How is this type of wave different from the water waves and rope waves? □□

From the thousands of experiments that scientists have done with waves, we know that all were either *transverse* or *longitudinal.* Think of your experiments with water waves. Which way did the cork move? Which way did the water move? In which direction did the water wave move? What kind of waves are water waves? Why?

Which way did the particles of rope move? Which way did the wave move down the rope? What kind of waves are these rope waves?

Which way did the slinky coils move? In which direction did the wave travel down the spring? Is this a transverse wave or a longitudinal wave? Why?

Sound and Sound Waves

We live in a world filled with sound and light. A world with many wonderful things to hear—the voices of our friends, the sounds of music, the songs of birds, and the wide variety of sounds that go to make up life as we know it. We live in a world with many beautiful things to see—green grass, trees, flowers, sky and ocean colors, and so many other things. Perhaps you have wondered about sound and light. If you have, then you're not alone. Man has been wondering about both of them for many centuries.

Can you imagine a world without sound or light?

IMAGINE

Close your eyes and cover your ears with your hands so that you can neither see nor hear. Sit that way for about a minute. Can you imagine what it would be like to be unable to see or hear anything? How could you learn about the world around you? How would you be able to communicate with other people?

DESCRIBE

Make a list of all the sounds that you hear right now. How are all of these sounds alike? How do the sounds that you hear differ from each other? Which sounds are most pleasant?

OBSERVE

Stretch a rubber band between your two hands, and pluck it with your thumb. What do you observe happening? Try to make several different sounds with the rubber band. What happens each time?

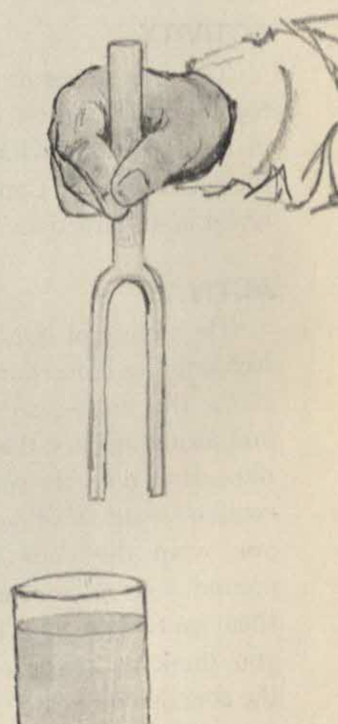
COMPARE

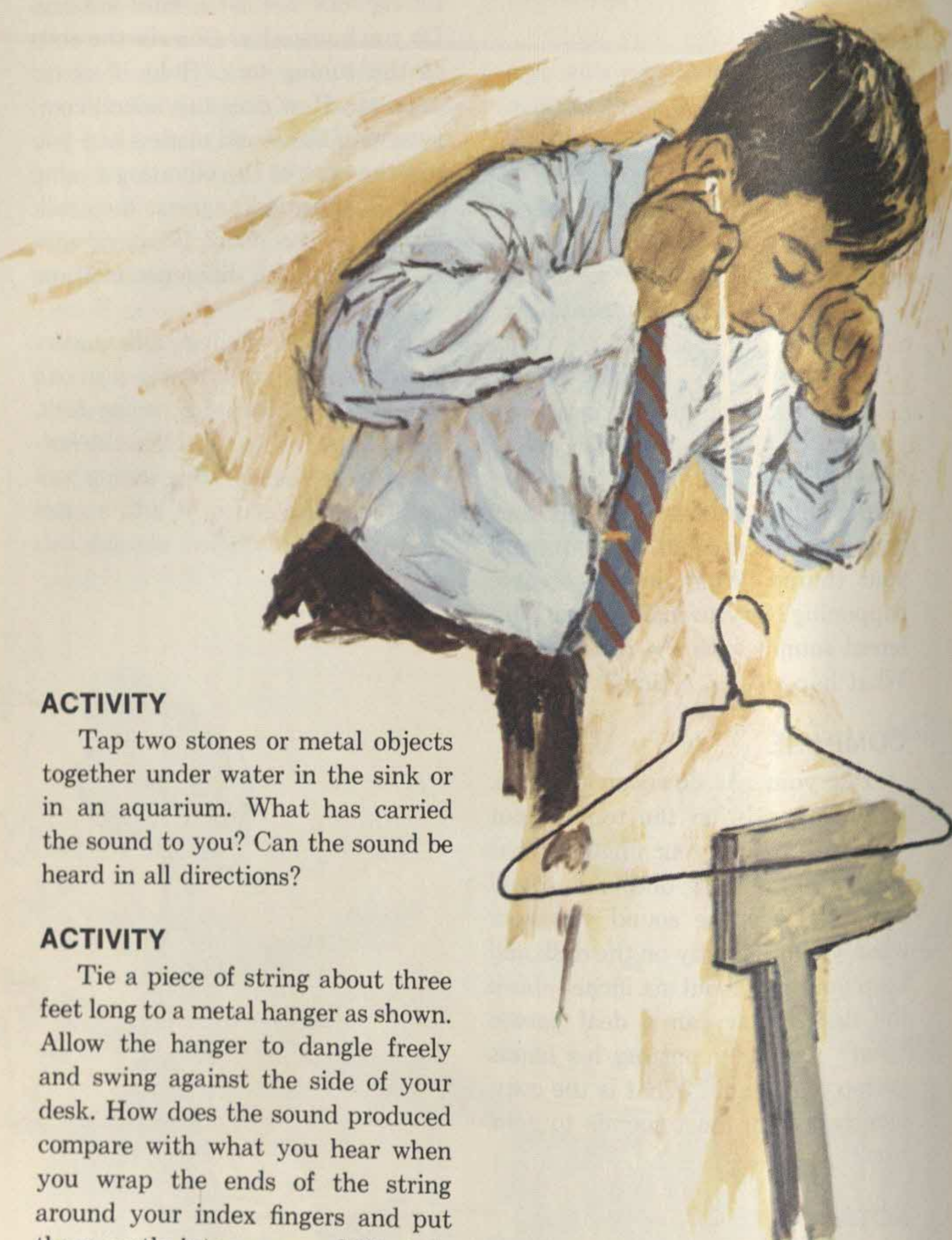
Put your ear down on the desk and tap gently on the top of your desk with one of your fingers. What do you hear? How does this sound compare with the sound you hear when you tap gently on the desk and keep your ear about six inches above the desk? How can a deaf person "hear" music by putting his hands on top of a piano? What is the common carrier of most sounds to your ears?

ACTIVITY

Strike a tuning fork with a hard rubber mallet or against your rubber heel. You should never strike a tuning fork against a hard surface. Do you know why? Observe the ends of the tuning fork. Hold it up to your ear. How does this sound compare with the sound made when you put the base of the vibrating tuning fork on your desk; against the chalk board; on the door? What do you think causes the difference in these sounds?

Strike the tuning fork again. Touch the surface of water with one prong of the vibrating tuning fork. What happens? Why? Hold the bottom part of the vibrating tuning fork and place the end of it into a glass of water. What do you observe this time?





ACTIVITY

Tap two stones or metal objects together under water in the sink or in an aquarium. What has carried the sound to you? Can the sound be heard in all directions?

ACTIVITY

Tie a piece of string about three feet long to a metal hanger as shown. Allow the hanger to dangle freely and swing against the side of your desk. How does the sound produced compare with what you hear when you wrap the ends of the string around your index fingers and put them gently into your ears? What do you think causes the difference in the sounds you heard?

COMPARE

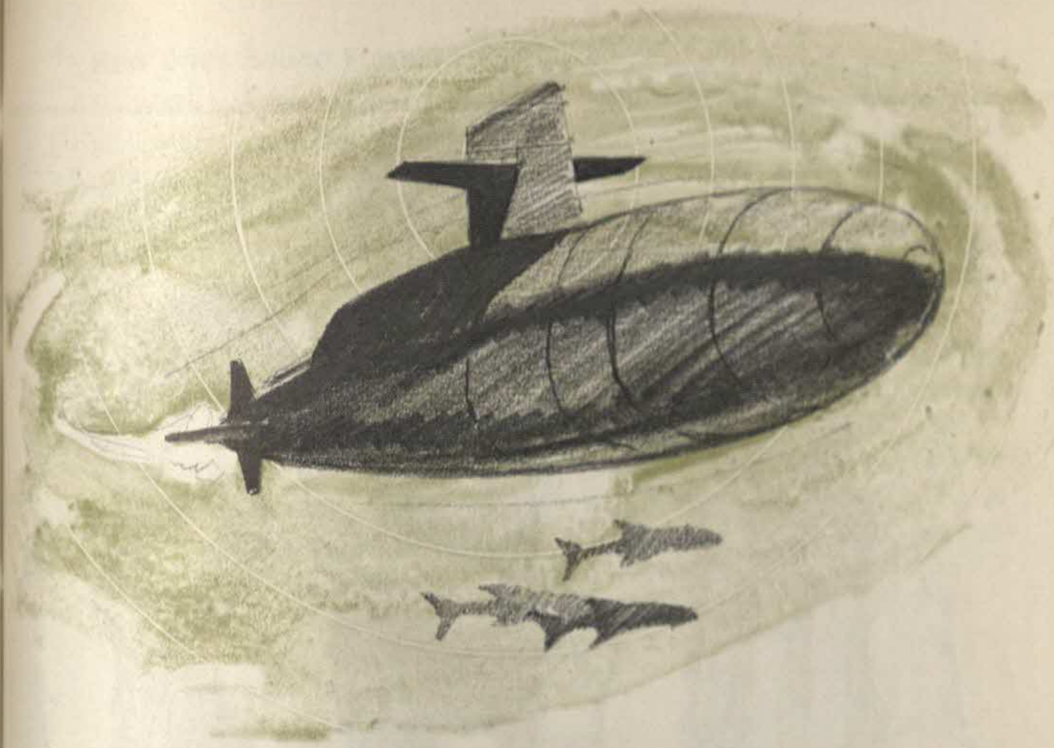
Cut off the neck of a balloon. Take a cardboard tube or round box and cover one end of it with the piece of the balloon. Use a string or rubber band to hold the cut balloon in place. Tap the rubber covering with your finger or the end of a pencil. What do you observe? Hold the tube with its rubber cover near your ear and tap the rubber drum with a pencil. Hold the tube on a table and tap the rubber drum again. How do the sounds compare? Hold the tube against a door and listen for this sound when the rubber drum is tapped. Fold a sweater several times and place it on a table. Hold the tube over the sweater on the table and tap the rubber cover. What do you observe? What do you think caused the difference in the sounds?

Obtain some salt or fine sand. Strike the rubber while the tube is on the table. While you still hear the sound, sprinkle the salt or sand onto the top of the rubber drum. What do you see? Repeat this part of the activity. This time, touch the rubber surface while you can still hear the sound. What happens this time? Why?

A Model to Explain Sound

In your activities you have listened to high and low sounds. You have heard loud and soft sounds. You have probably found that some sounds were pleasant and others were distinctly unpleasant and noisy. When you closed your eyes, you listened to a wide variety of different and interesting sounds; sounds that your brain has learned to interpret and remember. Do you suppose it is possible to construct a model that would help to explain these many differences? In making a model to help explain something that we observe, it is necessary to think carefully about our previous observations. Let's try to do just this. Think back about all of the activities that you have done which are related to making sounds. What did they have in common? Did you find that everything that makes a sound is moving back and forth? Make a sound with a ruler by strumming it while it is pressed down on your desk. Can you see the motion back and forth?

Each time a sound is made, something moves back and forth. If you put your hand on your "Adam's apple" and say a word, you can feel this motion. Whenever anything moves back and forth, we say it *vibrates* (VI-braytz). Vibration is a back and forth motion. Have you



discovered that vibrations occur in solids, liquids, and gases? Would you agree that sounds are caused by the vibrations of material objects? Would you consider it correct to say that sounds are caused by vibrations in matter?

You may feel that your answers are quite sufficient to explain the nature of sound. But remember, our model must not only be able to explain the origin of sound but it must also be able to explain all of the things we can observe about sound. To do this we have to think carefully again and try to look for further relationships.

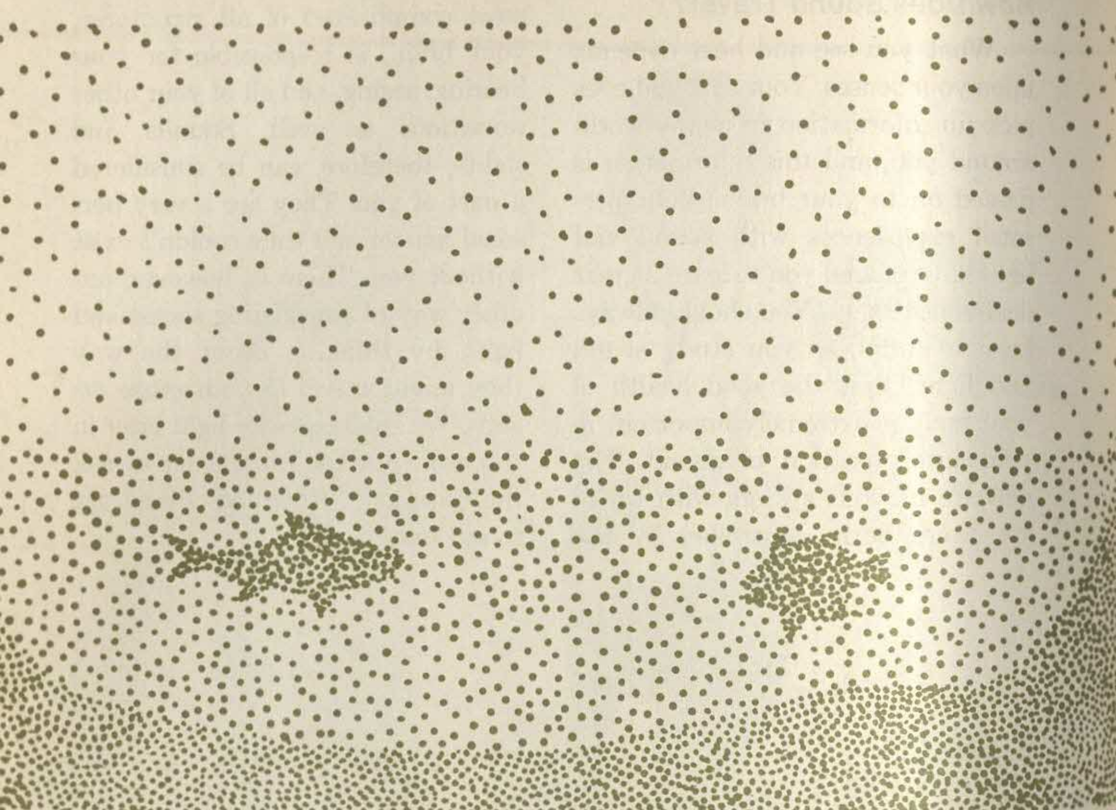
From the activities you have done, you should now be able to understand how sound is produced and the kinds of materials that carry sounds to you. Whenever there is a sound, something is vibrating. If a sound is produced at a distance from you, something must carry the vibrations to your ears. Since you live in an "ocean" of air that surrounds the earth, this air is the most common carrier of sounds to you. Air is not the only carrier of sounds. As you have observed, water, which is a liquid, can carry sound. Wood and metal can carry sounds too. Any gas, liquid, or solid may be a carrier of sound. Do you think all materials are good carriers of sound? Try to explain your answer with examples that can be demonstrated.

OBSERVE

Lay a metal waste basket over on its side on the floor or table top. Hold a candle in front of the open end of the can. Tap on the bottom of the basket gently, then forcefully. Look very carefully at the candle flame. What do you observe happening? What produced the disturbances in the air? Try placing a large megaphone, or a piece of heavy construction paper shaped into a megaphone, in front of the waste basket. What do you observe now when a flame is held in front of the cone as you tap on the bottom of the basket? How would you explain your observations in terms of the wave model of sound?

How Does Sound Travel?

What you see and hear depends upon your senses. Your ears and eyes pick up information from the world around you, and this information is passed on to your brain. Your personal experiences with sound and light have helped you to learn a great deal about them. You should always keep in mind, as you study sound and light, that the good health of your body is extremely important in your interpretation of sound. The delicate nervous system with which you were born, controlled by the most complicated of all structures, your brain, is responsible for your hearing, seeing, and all of your other sensations as well. Sounds and sights, therefore, can be considered a part of you. They are a very personal matter and they couldn't exist without you. There is, however, another way of considering sound and light, by thinking about the way they might travel to your sense organs. We shall consider light later in the unit. For the present let us ask the question, "How does sound get to our ears?"



Our Model Changes

It is now believed that most people who have studied the question, "What are things made of?", agree that matter is made of small invisible particles called atoms. These atoms often combine in various ways to form other slightly larger particles. Unit I of this book was devoted to an atomic and molecular model to explain the material world. Practically every substance in the world is either atomic or molecular in structure. Air is a mixture of different gases, all of which are composed of molecules. One way to imagine air is to think of billions and billions of tiny particles (the molecules found in air) too small to see, banging into each other as they move through space. What would happen to these particles if an object were to vibrate near them?

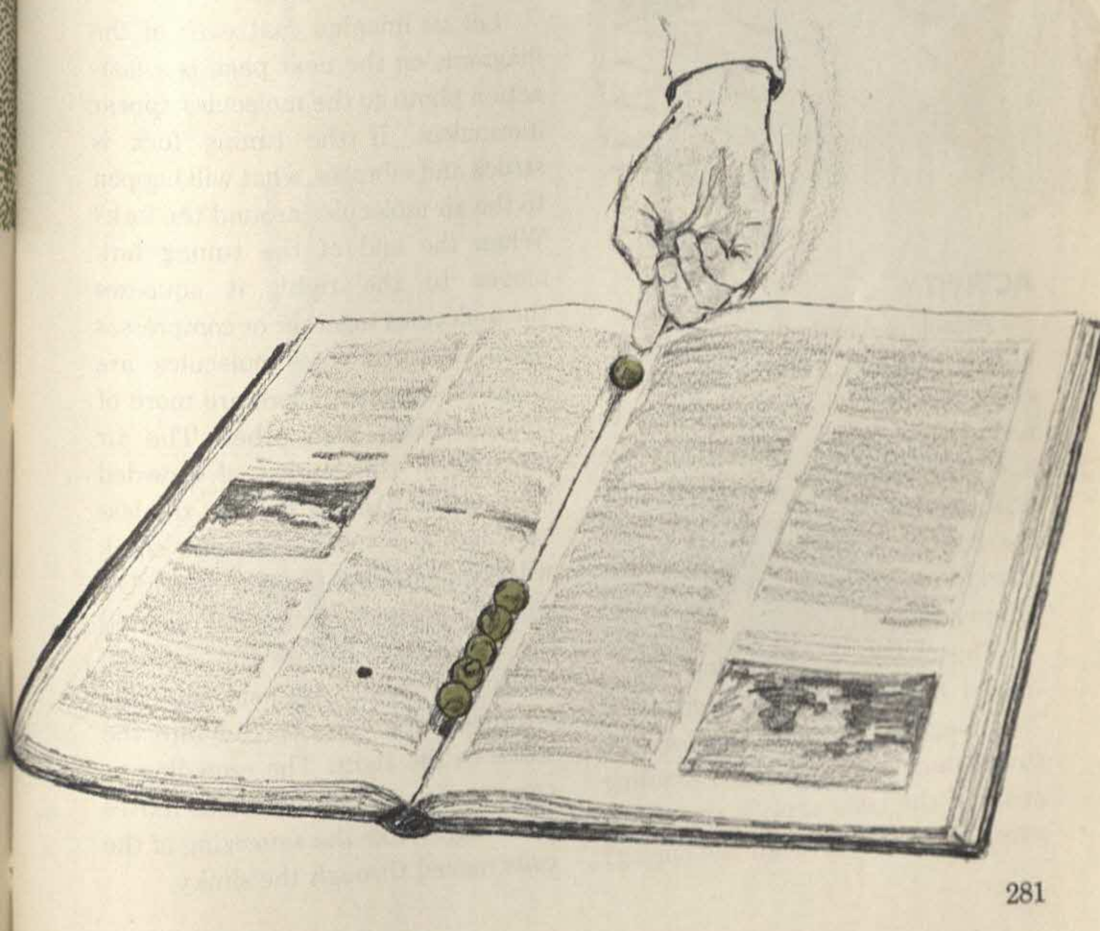
We can not see the particles that make up air but we can experiment with larger objects that we can see. Let's do some activities that will help us understand what is happening to the molecules we can not see with our eyes but which we can "see" with our minds.

OBSERVE

Line up 4 or 5 marbles in an open book, as shown in the picture. Strike the row of marbles with another marble as you roll it quickly at the line of marbles. What do you observe? In what direction does the disturbance travel through the row of marbles? How does this activity show what might happen to a group of molecules struck by other molecules?

Line five pennies in a single line. Take another penny and quickly flick it at the row of pennies. What happens? How is this activity related to the one above? □□

It seems reasonable to assume that a similar reaction occurs among molecules. When a vibrating object moves through the air, the molecules near it are disturbed in a regular fashion. This disturbance depends on the frequency of the vibrating object. Molecules are bunched up and spread out in a regular way. In this way, a wave forms and travels through the air. Although it is very difficult to imagine this happening, the following activity should help.



ACTIVITY

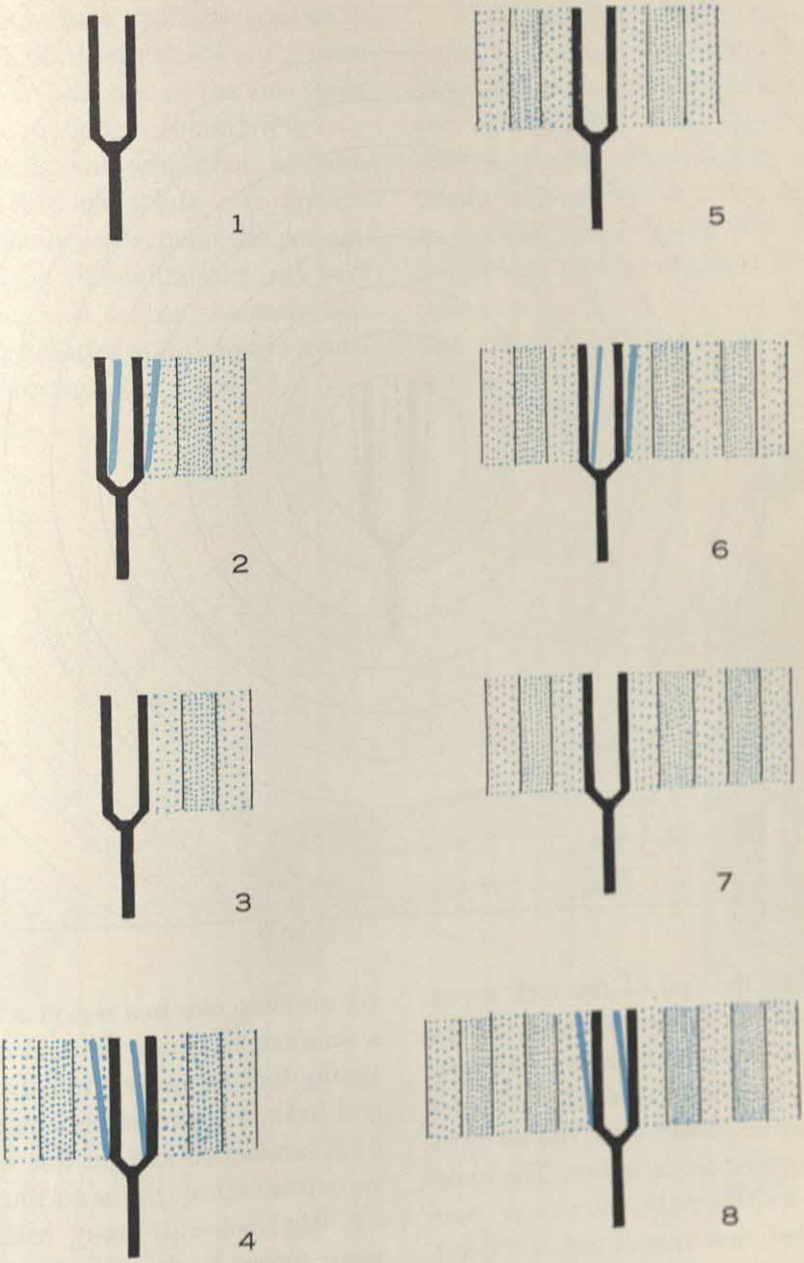
Attach one end of a slinky to one of the map hooks at the top of the chalk board. Allow the slinky to hang freely. If it is necessary, place a small weight on the free end. Squeeze 3 or 4 coils together near the bottom of the spring and then quickly release them. What do you observe happening? □□

The movement that you see is caused by the "bunching up" and "thinning out" of the coils. How does this coming together and spreading apart of the coils explain the movement of a wave through the spring?

Although the air molecules are not like tiny slinkies, the particles do seem to behave as if they were perfectly elastic.

The disturbance that traveled through the slinky after you released the squeezed coils helps you to "picture" what happens in the air which is disturbed by a vibrating object. With the aid of the diagrams pictured on the next page, let us do a "think" experiment. In diagram 2, the black dots represent the molecules of air that surround a vibrating tuning fork. These molecules are moving in all directions.

Let us imagine that each of the diagrams on the next page is a fast-action photo so the molecules appear motionless. If the tuning fork is struck and vibrates, what will happen to the air molecules around the fork? When the end of the tuning fork moves to the right, it squeezes the molecules together or compresses them. Because the molecules are crowded together, there are more of them pushing each other. The air pressure in this region of crowded molecules is greater than in the less crowded space. What do you think will happen next? Do you remember what happened when you released the squeezed coils? As the crowded molecules push against the less crowded ones, they spread into the space to the right. The crowding or *compression* of the molecules moves to the right, like the squeezing of the coils moved through the slinky.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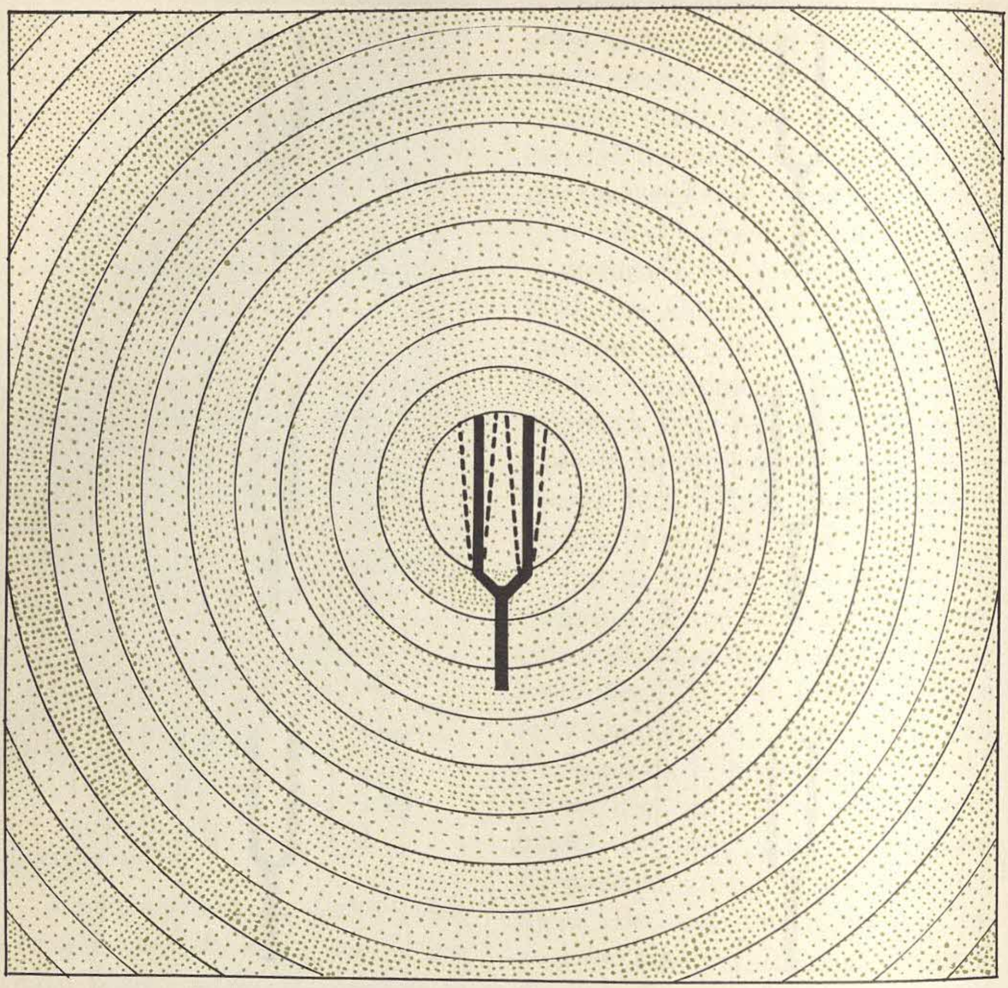


Now the end of the fork moves to the left on this one swing. As the air molecules move into this empty space, they are less crowded, because they have spread out. The air pressure in this space is less. The molecules to the right, that have been crowded, now spread out to the left. A thinning of the molecules, and hence a drop in air pressure, moves them to the right. This thinning of the air molecules in a region is called a *rarefaction*. Since the end of the tuning fork is moving rapidly back and forth, a compression is followed by a rarefaction and, in this way, a wave passes through the surrounding air. The molecules sway back and forth, moved by the vibrating tuning fork. A compression is always followed by a rarefaction, as the air moves. A sound wave moves outward

in all directions as the molecules vibrate. Think of the slinky. The molecules move back and forth parallel to the direction in which the sound wave travels. Which one of the two types of wave motions is sound? Why?

Sounds, you remember, can also travel through solids and liquids. How would you explain the passage of a sound through a long iron bar? Are you able to use the molecular model of matter and the wave model to explain sound?

Does Every Vibrating Object Produce Sound?

Move your arm slowly back and forth. Your arm is vibrating. Do you suppose this produces condensations and rarefactions? Why don't you hear a sound? Experiments with people have shown that the smallest number of vibrations that most people can hear is about 20 vibrations per second. It was also found that the highest number of vibrations a person can hear is about

20,000 vibrations per second. Sound waves with a frequency less than 20 vibrations per second, vibrating too slowly to hear, are called *infrasonic* (in-fra-SAHN-ick). Sound waves over 20,000 vibrations per second, vibrating too fast to hear, are called *ultrasonic* (ul-truh-SAHN-ick).

You can buy a special kind of whistle for your dog. You can blow and blow, and you hear nothing. Your dog, however, can be trained to come running at this "sound." Many animals have a wider range of sound vibrations than man. Why do you suppose sound is so important to animals? Scientists have learned that cats and dogs have a hearing range up to 30,000 vibrations per second. Do you think it interesting that these two animals have about the same hearing range? Bats can make a sound of about 50,000 vibrations per second, and they can detect sounds up to a range of 100,000 vibrations per second.

You will recall that the number of vibrations per second of a wave is called the frequency of the wave. The differences in the frequency of the sounds you hear is one cause of the variety of sounds around you.

The Frequency of Sound Waves

One of the important characteristics of all energy waves is frequency. What happens to sound as we vary the frequency of the vibrating object?

LISTEN

Take a ruler and place it on your desk with about five inches sticking out over the edge of the desk. Holding one end of the ruler firmly on the desk at all times, press down on the projecting end and then let it go. Listen carefully to the sound. Do the same thing with the ruler sticking over the edge 1 inch, 2 inches, 3 inches, 6 inches, 7 inches, etc. As you looked closely at the ruler, did you notice anything happening to its rate of vibration as you plucked it in different positions? What did you hear happen to the sound as you moved the ruler in and out on the desk? Try this activity again to be sure. According to our model, what happens to the air molecules as the ruler vibrates up and down? What happens to the frequency of the sound waves produced as you worked with your ruler in different positions on the desk? When were the highest and lowest frequencies produced? What must you do to produce louder sounds? □□

In talking about the "highness" or "lowness" of a sound, the term *pitch* is commonly used. Can you think of some high-pitched sounds? What are some examples of low-pitched sounds? Make a list of 10-20 common sounds that you hear. List the sounds from the highest-pitched to the lowest-pitched. What happens to the pitch of a sound as the frequency of the vibrating object increases? What happens to the sound when the frequency of the vibrating object is lowered?

What is the frequency of this tuning fork?

Tuning forks are valuable aids in the study of sound and sound waves. One of the most valuable things about them is that the frequency of the sound waves that they produce is usually marked on them. Examine a tuning fork. Can you locate the frequency number? A tuning fork that is stamped with the number 256 produces 256 vibrations per second. This means that during each second that the tuning fork is vibrating, 256 compressions and 256 rarefactions will be produced in all directions, in the molecules of air surrounding the tuning fork. This tuning fork is said to produce sound waves with a frequency of 256 vibrations or *cycles* per second. Each cycle consists of a compression and a rarefaction produced by one back and forth movement of the tuning fork prongs.

PREDICT

Can you predict which of two tuning forks will make a higher pitched sound by reading the numbers on them? Obtain a tuning fork which produces 256 cycles per second and one which produces 288 cycles per second. Predict which one will produce the higher sound. Strike both forks and listen. How do your observations compare with your prediction?

MEASURE

Take an empty 8-inch test tube and blow across the open end. What is vibrating to produce the sound

that you hear? Is the tube really empty? Pour one inch of water into the test tube. Measure accurately with your ruler. Blow across the top again. Do you notice anything different about the sound produced? Using your ruler to measure, add water to the test tube, one inch at a time, blowing across the top of the test tube after each addition of water. What happens to the pitch of the sound as water is added to the test tube? Can you tell why?

COMPARE

Stick six thumb tacks into a flat piece of wood. Then take rubber bands and stretch them between the tacks. Thick rubber bands work best. Wrap the rubber bands around the tacks and make sure that the tension on each one is about the same. The rubber band stretched between the closest pair of tacks should be just as taut as the one stretched between the pair of tacks which is farthest apart. Pluck each one of the rubber bands with your finger. What do you notice about the sounds produced? What relationship exists between the length of the rubber band and the pitch of the sound produced?

Stretch a thick rubber band between your two hands. Pluck a part of the rubber band with one of your thumbs. As you do this, hold the rubber band up near your ear. What do you hear happening to the pitch as you increase and decrease the tension on the rubber band?

OBSERVE

Look up at your teacher's desk. You've done enough experimenting for a while. Now let's watch a demonstration and see how much you have learned about sound. Notice that each bottle has a different amount of water in it. Can you predict what will happen when somebody blows across the top of each bottle or taps each one with a wooden mallet or stick? Which bottle will produce the lowest pitch sound? Which one will have the highest pitch? □□

The inside of a piano is a very interesting thing to see. You can learn several things about sound by examining it. If a piano is available in your school, and your class obtains permission, it would be valuable to try the following activity.

ACTIVITY

Strike the tuning fork marked 256 and locate the note on a piano which corresponds to the pitch produced. What note is it? Strike another tuning fork and see which note it corresponds to. Have your teacher open the piano. Look carefully at the parts inside. How are the sounds produced by a piano? Can you explain this in terms of the wave theory of sound? What do you notice about the "strings" inside the piano? Compare a string which produces a high-pitched sound with one that pro-

duces a low-pitched sound. If two piano strings were of the same length, thickness, and made of the same material, how might you get them to produce sounds with varying pitches? □□

The Doppler Effect

Have you ever noticed the pitch of an automobile horn or a train whistle rise as the car or train approaches you? This is called the *Doppler Effect.*

It was first explained by an Austrian physicist, Christian Doppler, in 1824. The following activity may help you arrive at an explanation.

ACTIVITY

Securely fasten a small alarm clock to the end of a 4-5 foot piece of rope. Make sure to have the clock tied in such a way that it can be safely whirled in a circle without coming off. Listen carefully to the pitch of the ringing alarm clock when it is on the table top. Whirl the ringing alarm clock in a circular path around your head. What do observers, standing about 10 feet away, notice about the pitch of the alarm as the clock approaches them? Can you explain this?

When the alarm clock is standing still on the table top, you receive

a certain number of sound waves per second. This number is called the *normal frequency*. But what happens when the clock is moving toward you? Is the pitch of the alarm higher or lower? Are you still receiving the normal frequency? Are you receiving more or less vibrations per second? Can the velocity of motion have an effect on the pitch of a sound? Why?

The Amplitude of Sound Waves

If you were describing a sound you had heard, you would most probably say whether it was a high- or a low-pitched sound. But perhaps the first thing you would say would have to do with whether it was loud or soft.

Our wave model, if it is to remain satisfactory, should also be useful in explaining the loudness and softness of sounds. How are these differences in sounds related to waves? How are loudness and softness related to energy? Perhaps you already have answers to these questions. If you do, write them down as predictions and then try the following activity.

ACTIVITY

Produce sound waves by strumming a ruler, blowing into an 8-inch test tube, plucking a thick rubber

band, and striking a tuning fork. In each case do what is necessary to produce sound waves, as gently as you can at first. Slowly increase your efforts. Be careful not to increase your efforts too much at any time. Too much effort may produce unwanted sounds, and may result in damage to the tuning fork or other instrument that you are using. What do you observe happening to the sound produced in each case? Would you say that the energy of the sound waves was increasing? Can you think of a way to prove your answer? What do you notice about the pitch of the sounds produced as you increase your efforts? How is the loudness of the sound related to the energy necessary to cause it? Do you remember your earlier experiments with the rope waves? How did you increase the amplitude of the waves traveling through the rope? □□

How do you suppose the amplitude of the sound wave is related to the loudness of a sound? How is the amplitude of a sound wave related to the energy that caused it?

Loudness and softness are directly related to the amplitude of sound waves. Would you agree that the amount of energy which sound waves have, determines the loudness or softness of the sounds that you hear?

The Velocity of Sound Waves

Earlier in this unit you calculated the velocity of rope waves. It is possible to do the same thing for sound waves. Have you ever seen a baseball player from across a field hit a ball and, after a short delay, heard the crack of the bat? Perhaps you have seen a man chopping wood in the distance, and you noticed that his movements seemed to be a few seconds ahead of the sounds that you heard. In the next activity you can make an observation of this kind to help you calculate the velocity of sound.

ACTIVITY

Have one of your classmates go to one end of a large playground or field with a metal can and a hammer. Have him bang on the can loudly enough so that it can be heard from a distance. Your classmate should be about 300 feet away. Have him strike the metal can sharply and then bring his arm quickly to an upright position. □□

What you see from across the field is the result of light reflected from your classmate and traveling to your eyes. What do you notice about the velocity of sound compared to the velocity of light? Which travels faster, sound or light?

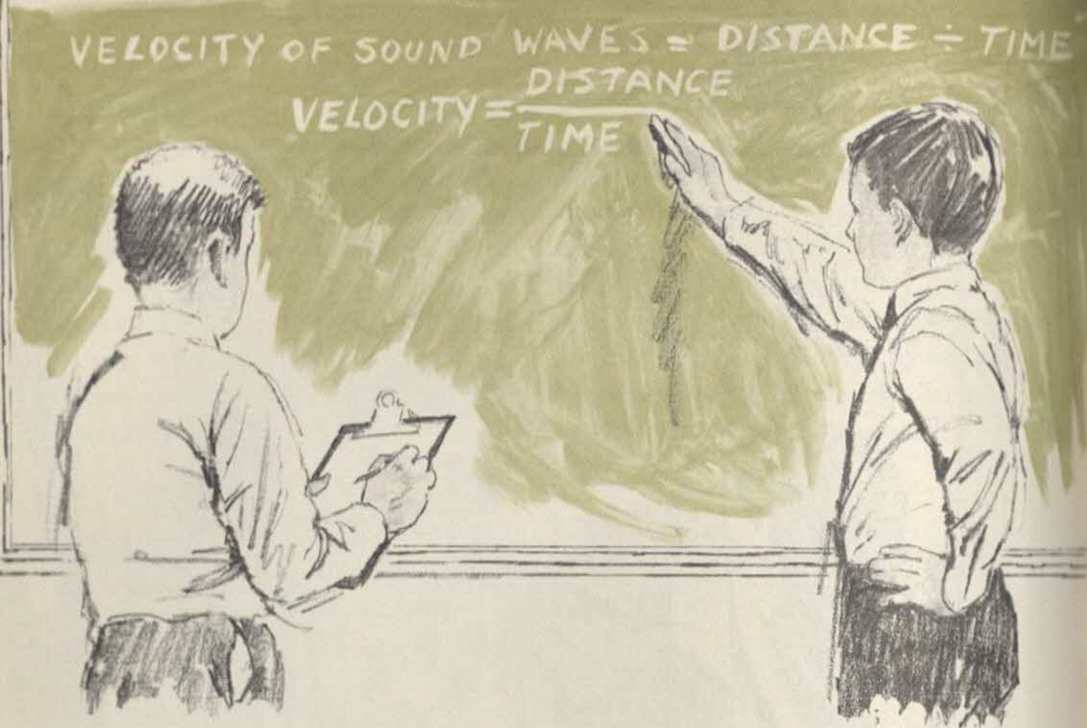
Scientific experiments have determined the velocity of light waves in the air to be about 900,000 times faster than sound waves. In fact, sound waves travel slowly enough so that it is possible for you to measure them directly with a stop watch. You can assume for this activity that light comes to you from an object without delay.

ACTIVITY

In a large open area, use a tape measure to carefully mark off a distance of about 2,500 feet. This time, have one of your classmates bang the metal can at one end of the measured distance, while you stand at the other end with a stop watch. When you see the hammer strike the can this time, start your watch. Stop the watch as soon as you hear the sound. Repeat this activity five times. Find the average time it took the sound waves to travel from the can to you. Since you measured the distance the sound waves traveled, you now have enough information to determine their velocity. To calculate the velocity, divide the distance by the time. What is the velocity for

sound waves that you have determined? □□

A sixth-grade class in Hawaii used the following method for determining the velocity of sound. At noon every day, the whistle would blow in a nearby factory. The factory was located exactly 2.1 miles from the school. This distance had been determined by driving down a straight road between the school and the factory and checking the distance traveled on the car's mileage indicator. Just before noon one day, one of the students called the factory and asked to be connected with the room where the noon signal was set off. The student knew that a voice can travel over the telephone without delay. He was then told the exact instant that the signal was set off. A stop watch was started, and



then stopped as soon as the signal was heard at the school. The students' calculations are shown below:

Distance traveled by sound waves = 2.1 miles or 11,088 feet ($2.1 \times 5{,}280$ feet = 11,088 feet)

Time for signal to get from factory to school = 9.7 seconds.

Velocity of sound waves = Distance ÷ Time

$$\frac{\text{Distance}}{\text{Time}} = \frac{11{,}088 \text{ feet}}{9.7 \text{ seconds}}$$

Velocity of sound waves = 1,140 feet per second.

Since the temperature was about 83° F., their determination was remarkably accurate! How does your calculated velocity compare with what these students observed? You have been exploring three characteristics of sound waves—frequency, amplitude, and velocity. In the next section, another important characteristic of energy waves will be explored.

The Wavelength of Sound Waves

Perhaps you remember the difficulties you had determining the wavelength of rope waves. It is also difficult to measure the wavelength of sound. Since you cannot directly observe a sound wave, an indirect method for determining the wavelength must be used. Below is a formula to help you determine the wavelength of sound.

The wavelength of a sound wave is equal to the velocity of the sound divided by its frequency. Mathematically this can be written as:

$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

This same statement can be written $W = \frac{V}{F}$ where W represents velocity, and F stands for the frequency of the sound wave. This relationship among wavelength, velocity, and frequency seems to be true for all waves.

In their study of sound and sound waves, the sixth-grade class in Hawaii did another interesting thing when faced with this problem of finding wavelength. They noticed that the sound of the factory whistle was almost exactly the same pitch as one of their tuning forks which was known to produce 320 cycles per second. They correctly assumed that the factory whistle also produced 320 cycles per second. This meant that the whistle and the tuning fork had the same frequency. Having previously determined the velocity of the sound waves, they now had enough information to use their wavelength formula. Their calculations are shown below:

Velocity of sound waves = 1,140 feet per second

Frequency of sound waves = 320 cycles per second

$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

$$\text{Wavelength} = \frac{\text{1,100 feet per second}}{\text{320 vibrations per second}}$$

Wavelength = 3.6 feet

Their calculations showed that the distance between each wave produced by the siren blast was 3.6 feet. They could not observe this directly but they felt quite sure about the indirect method that they had just used.

Earlier in this unit, you were given an opportunity to observe the velocity of waves moving through a rope. No matter what the amplitude or frequency of the rope waves happened to be, the velocity through the rope remained the same. The same thing is true for other waves including sound. Of course, this assumes that the substance through which the waves are traveling remains the same. Would the velocity of the rope waves be the same if you used a different kind of rope? Try it and see.

PROBLEM

The velocity of sounds produced in the school auditorium was measured and found to be 1,130 feet per second. During an assembly program, a student strikes middle "C" on the piano. Remember, middle "C" has a frequency of 256 vibrations per second. What is the wavelength of the sound coming from the piano? Would the wavelength of the sound

waves produced by a 256 cycle per second tuning fork be the same? If you hummed a tone at this pitch would the wavelength be the same? Why? □□

The wavelength of a sound wave can also be determined by using another characteristic of energy waves which was not considered in our work with rope waves. Try the following activity to discover what this characteristic is.

LISTEN

Hold a wristwatch in your hand, close to one of your ears so that you can hear it ticking. Move it away slowly to the position where you first notice that you can no longer hear it ticking. Place a 5×7 file card, curved and held in your other hand, on the other side of the watch as shown in the picture. Move the file card in close to the watch and then slowly move it away. Make sure that you do not move the watch. Move the card in and out several times. What do you hear? Do you see any similarity between this observation and the one you made using a megaphone to focus sound waves? What happens to the sound waves when they strike the curved file card?

Echoes

Have you ever called out or made sounds in an empty room and heard the sounds again? Sound waves can be bounced back from objects in their path. These reflected sounds are called echoes. What do you suppose caused the repeated sounds in the empty room? Why are echoes considered good evidence for the existence of sound waves? Try to find

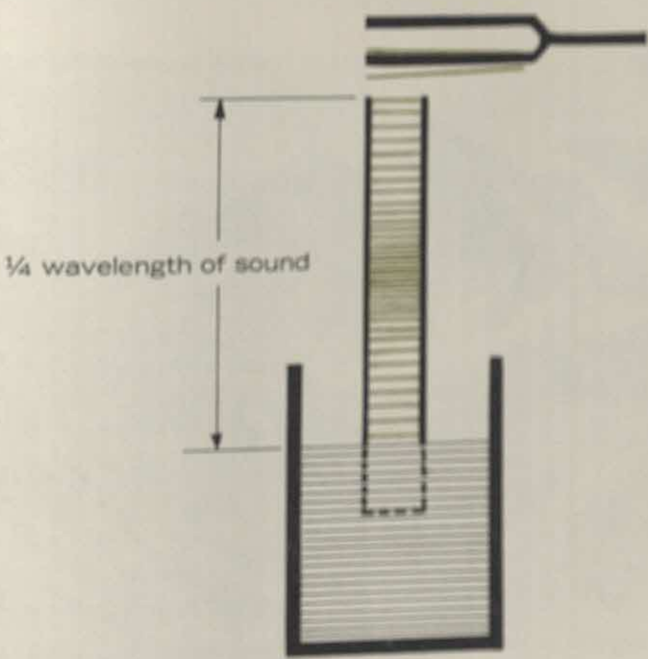
places in your neighborhood where echoes can be produced. If possible, bring a stop watch and make observations of different echoes. What characteristics of echoes can you describe? How are they like the original sound? Can you make up an experiment to determine the velocity of an echo?

ACTIVITY

Make a tube about 20 inches long and about 2 inches in diameter, using heavy construction paper. A mailing tube or a piece of pipe about this size can also be used. Place one end of the tube about one inch below the surface of water in a pail. Now place a vibrating tuning fork above the open end of the tube. Slowly push the tube down into the water while one of your classmates strikes the tuning fork with a rubber mallet to keep it vibrating. Try this activity, first using a 256 cycle tuning fork. What happens to the sound when about 13 inches of the tube is above water? Try this same activity using a 288 cycle tuning fork. At what point do you observe a change in the sound? What do you discover when other tuning forks are used? Do you see any similarity between this and the previous activity? What characteristic of energy waves could be reinforcing the sound produced by the tuning fork? Do waves interfere with each other? □□

The scientific term used to describe what you have just observed is called *resonance*. Resonance occurs when the frequency of a sound wave matches the normal frequency at which the object vibrates. What substance was made to vibrate by the tuning forks in the previous activity? When the normal vibrating frequency of the column air was the same as the vibrating frequency of the tuning fork, the sounds reinforced (helped) each other to produce a louder sound. This condition of resonance will occur when the length of the tube out of water is one-fourth as long as the wavelength of the sound waves being produced. Can you now calculate the wavelengths of the sound waves produced by the different tuning forks?

You have been working with a number of different materials in a wide variety of activities. This was done to help you create a model to help explain sound. You have had only a relatively small number of experiences with waves, and their relationships with energy. Yet it is not impossible to see that sound and waves are distinctly related, and that waves of all kinds seem to share certain important characteristics. It is possible that you can create a



different model to help you understand sound.

Your model will only be acceptable to others if it simplifies the explanation of a wide variety of observations and can predict what will happen under similar conditions in the future. It is for this reason that most scientists believe in the wave model of sound. Although molecules cannot be directly seen, scientists have every reason to believe they exist. They also have reason to believe that waves of energy move outward as these particles are alternately compressed and rarefied. The waves, which can be thought of as something physical happening to matter, reach your ears. The information carried by the waves then travels by way of nerves to your brain. What you hear as sound depends on each of these steps along the way.

Light and Energy

The main source of light for the earth is the sun. There are, however, other sources of light that you are quite familiar with—burning wood or other materials, and stars. Can you think of any other sources of light? Are there any differences in how light is produced in the sources of light that you can think of?

One of the most easily seen objects in the night sky is the moon. Is there any difference between

moonlight and sunlight? How is moonlight produced? Bodies that produce their own light are called *luminous* bodies. Is the moon a luminous object? Is the sun a luminous object? List all the luminous objects that you can think of. List all the objects which reflect light that you can think of. Which list is longer?

The sun is our most important source of energy. It has been said that without the energy from the sun, life as we know it would not exist. Do you agree with this statement? Why? Can you think of some other things that happen because of the energy which comes from the sun? The next few activities will help you answer this question.

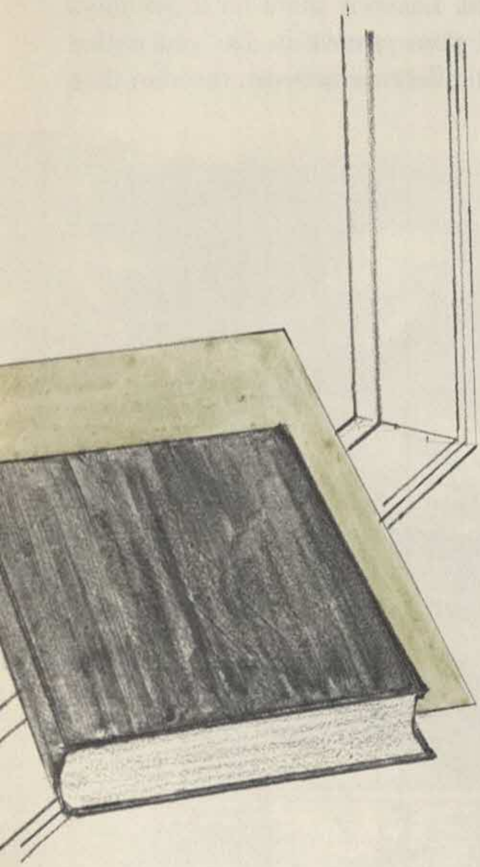
ACTIVITY

Put a piece of adhesive tape about an inch square on the back of your hand. Leave it there for a few days and then remove it. Do you notice any difference between the skin that

was covered and the surrounding skin? Suppose that you were to do this just before you went out to spend a summer day on the beach. Would you see more of a change? Why?

COMPARE

Take a small piece of colored construction paper and put it on a window sill or table where it will be in sunlight. Cover about half of the construction paper with a book and leave it that way. After several days compare the covered portion of the paper with the area that was left uncovered. What do you observe? What do you think caused this to happen? Take a good look at some of the covers of the older books in your library. Do you see any difference between the parts of the cover which have been exposed to light and the parts which have not?



EXPERIMENT

Have you ever noticed the effects of sunlight on green plants? Plant some fast-growing seeds (radish, lentil or oat) in two milk containers filled with soil. When the seedlings are about an inch tall, cover one of them with a box that has a hole in one side. Leave the other seedling uncovered. In the morning and in the afternoon look at the plant growing under the box. Make sure that you always put the box down with the hole facing in the same direction. Do you notice any difference in the direction of growth of the seedlings? After about a week, turn the box so that the hole faces in a different direction. As you continue to check, do you notice any changes in the direction of growth of the covered plant? What conclusions can be drawn from what you and your fellow students have observed in this activity?

CHECK

See if you can find other examples of sunlight affecting plants. Turn house plants or change their position in a room occasionally. Do you

What do you suppose caused this plant to bend in this way?

notice any changes that take place in the plants? Look carefully at trees growing near buildings which may keep sunlight from affecting all sides of the tree equally. Which sides of the trees show more evidence of branching? What do you think causes this? Can you think of other activities or experiments that you might do to find out more about sunlight and living things? Does sunlight affect animals as well as plants? Could you set up an experiment using some laboratory animals to determine the answer to the previous question?

In these activities you were able to make a number of observations about the light that reaches the earth from the sun. What evidence do you have that sunlight is a source of energy?

ACTIVITY

Close your eyes and move your head from side to side. Were you able to see anything while you were doing this? Of course not! But was there light around you? The answer to this question is obvious, but it illustrates a very important fact about vision and light. Can you tell what this fact is? □□

People have been aware of this fact about light for a long time, and over the centuries light has been studied in a variety of ways. The Greeks, as long ago as 300 B.C., were conducting some interesting investi-

gations. You can discover some of the things that they knew by doing the following activities.

OBSERVE

Look through a piece of rubber tubing about 12 inches long at a lighted candle placed on the teacher's desk. First stretch the tubing straight and hold it in line with the source of light. Can you see the candlelight? Then let the tubing sag so it hangs limply in the middle. Try to see the light now. What happens? Try doing these same things in different parts of the room. Are the results the same?

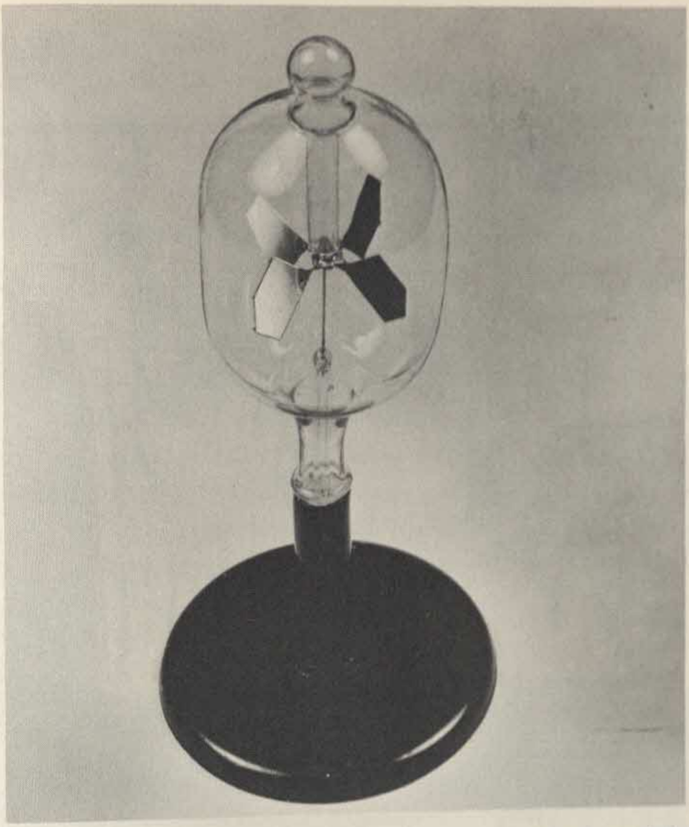
ACTIVITY

Take three file cards (3″ × 5″) and make a small hole with your pencil in the center of each card. Do you know how to find the center of each card? Fold the cards carefully until each card can remain upright on your desk. Arrange the upright cards so that you can see a pencil mounted in a piece of clay by looking through the three holes in your cards. Can you still see the pencil when you move one card slightly to the side? Would you agree that light travels in straight lines? □□

The ancient Greeks believed that light was something that traveled from one place to another even though they did not know what it was. They also believed that light traveled from the person's eyes to the object seen. How might you test this idea?

Energy is a word used very frequently by many people. You have probably heard of energy foods and advertised products that promise energy for your work and play. You probably have some energetic friends and you know about people who seem to be completely lacking in energy. Energy is a very useful word to scientists too. The word energy often reappears whenever scientific explanations are presented.

The model we have used to explain sound was based on the idea that energy can move from place to place. Scientists have agreed to use the word energy to stand for the *ability to work.* Work, remember, is the ability to push or pull something a definite distance.



When do the blades of a radiometer spin most rapidly?

Can Light Do Work?

Obtain a radiometer. A radiometer is a set of blades painted black on one side and silvered on the other, and arranged so as to turn freely in a vacuum. Watch the blades when the radiometer is in the presence of light. Now place the radiometer away from any very bright sources of light. What do you observe? When the blades are perfectly still, allow a beam of light to fall on the blades of the radiometer. What happens now? Does this demonstration show that light is a form of energy? Does heat affect a radiometer? How can you find out?

The Behavior of Light

What happens when light strikes different objects? You may be tempted to say that the light bounces from the object and is reflected back to our eyes. This is true. If you have ever searched for anything in the dark with a flashlight you have already learned something about reflection. You have probably reasoned too, that this is the only way to see an object in the dark, unless, of course, it is an object that gives off its own light. In order to observe the behavior of light as it interacts with different objects, try the next activity.

OBSERVE

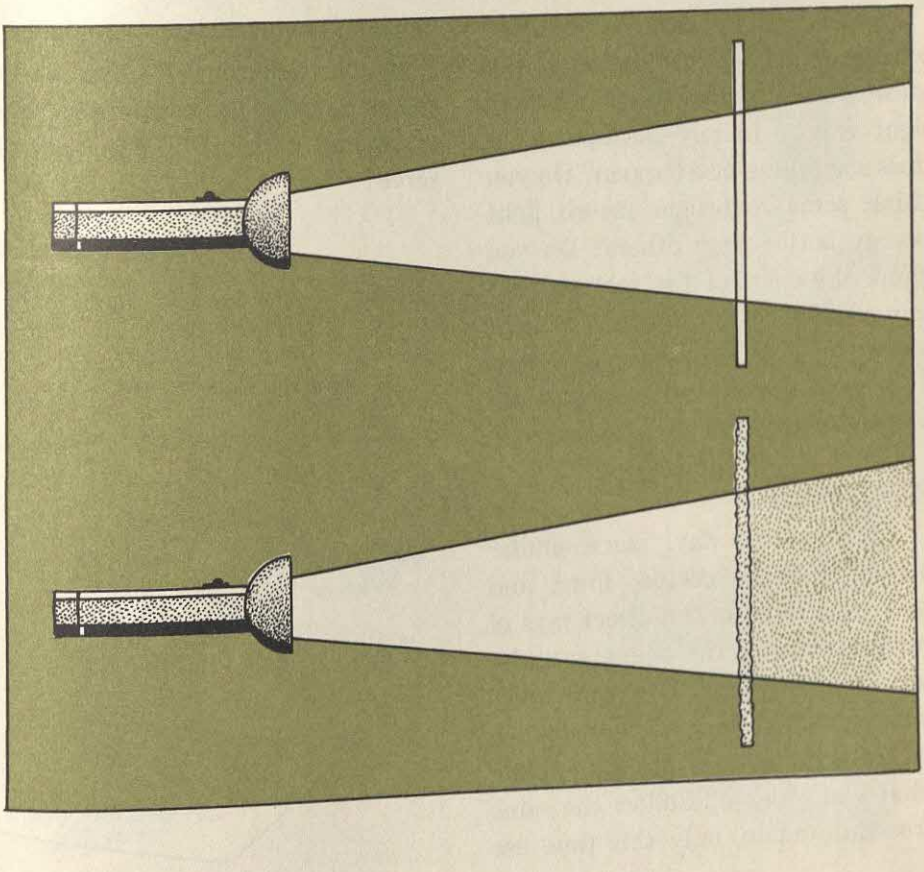
Using a flashlight in a darkened room, test as many different materials as you can find around your home or classroom. Include in your group of materials some of the following: sandwich wrap, tissue paper, cloth, water, milk, wood, aluminum foil, notebook paper, colored plastic sheets, glass, a book, cardboard, tracing paper, cellophane, a plastic bag, a paper bag, and some chalk. Can you arrange the objects in meaningful groups? Did you observe light passing completely through any of the materials? We say that such objects *transmit* almost all of the light that falls upon them. Which materials transmit only part of the light? How many materials prevented all of the light from passing through? In what other ways might you group your sample materials? Which group is largest?

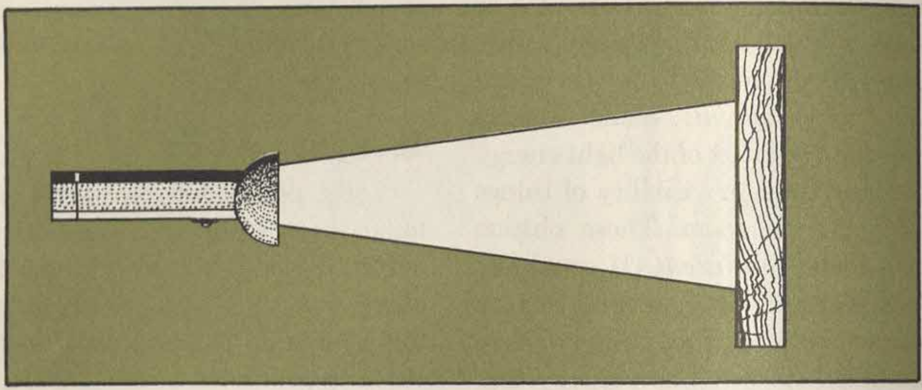
Transmission of Light

One way to classify objects is based on the degree to which light passes through them. Those objects through which light passes so readily that we can see through them are called *transparent*. Some objects transmit only part of the light energy but prevent clear visibility of things seen through them. These objects are called *translucent*. If an object does not transmit light and objects can not be seen through them, they are called *opaque*. Light energy that is not transmitted is reflected and absorbed in different amounts by the object. Can you think of an object or substance that will transmit, absorb and reflect light energy at the same time?

Absorption of Light

Light passes through some materials very easily (the good transmitters). Light can be reflected by other materials (the good reflectors). Actually, it is impossible to get 100% transmission or reflection.

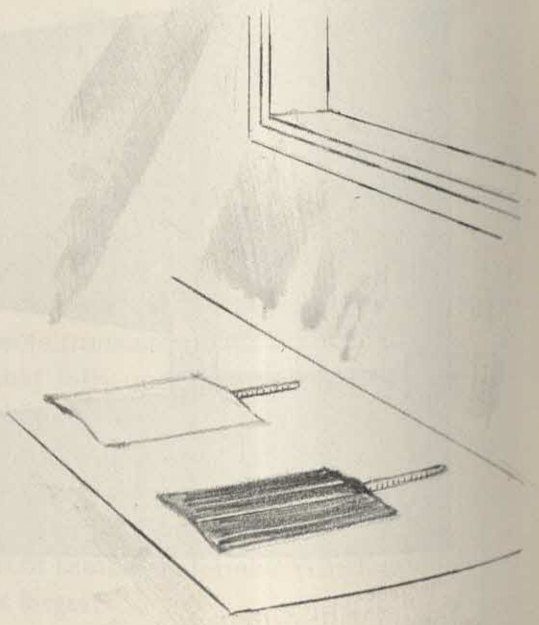




Some light is always absorbed whenever it strikes the surface of any substance. Do you think absorbed light energy merely disappears, or does something else happen? Do you think some materials absorb light energy better than others? Do you think the color of the material has any effect on the absorption of light energy? Try the following activities and see if you can discover the answers to these questions for yourself.

EXPERIMENT

On a sunny day, place similar pieces of white cotton, linen and wool on a table in the direct rays of sunlight. Place a thermometer under each piece of cloth. After five minutes, observe the temperature on each thermometer. Can you explain what you observe? Follow the same procedure again, only this time use black and white pieces of each cloth. What do you observe this time? Try the same thing with different pieces of colored paper. What do you observe?



Reflection of Light

ACTIVITY

In a darkened room, shine a narrow beam of light directly at a plane mirror. The beam of light will be more visible if you shine it through some chalk dust obtained by banging two board erasers together. Change the angle with which the light beam strikes the mirror. The beam of light approaching the mirror is called the *incident* beam. Can you observe a relationship between the *incident* beam and the *reflected* beam of light? Shine your beam of light on a variety of other surfaces. Try the wall, the top of your desk, a piece of aluminum foil, your handkerchief, a window pane, a piece of rock, a handful of sand, and other things. What do you observe?

When a beam of light is reflected from a smooth surface such as a plane mirror, it is called *regular reflection*. Most of the objects that you used produced irregular or *diffused reflection*. What objects produce regular reflection? What do these objects have in common?

Arrange your light source, a plane mirror, and a protractor on a sheet of white paper as shown in the picture. The protractor should be centered directly over a line drawn perpendicular to the mirror. The narrow beam of light should be reflected off the mirror at the point where the perpendicular line touches it. Position the light source so that angles of incidence of 20°, 40°, and 80° are produced. What angles of reflection are produced for each of these angles of incidence? Check your figures. How do your results compare with what your classmates found? What is the relationship between the angle of incidence and the angle of reflection of light? □□

When light is reflected from a smooth surface, the light that reaches your eye seems to be coming from behind the reflecting surface. What you see is an *image* formed "behind" the surface. The next activity has been designed to give you an opportunity to explore images further.

OBSERVE

For this activity, instead of an ordinary plane mirror, let's make one that will serve your purposes better. Your mirror will be a small piece of window glass mounted upright in a piece of clay. Place a small lighted candle exactly 12 inches away from the glass as shown in the picture.

When you stand behind the light source, can both you and a partner see the image of the flame formed in the piece of glass? While you continue to look at the image in the glass, have your partner move a sheet of paper on the other side of the glass until the image of the candle flame seems to fall exactly on the paper. Measure the distance from the glass to the sheet of paper. Now switch places with your partner and let him guide you until he sees the image of the candle flame formed on the sheet of paper. Again measure the distance from the glass to the paper. How does the image's distance behind the mirror compare with the object's distance in front of the mirror? Does this relationship remain the same when you change the distance from the candle to the glass? Why did you use a sheet of glass instead of an ordinary plane mirror? How do the results of your experiment compare with what the other boys and girls in your class found out? What is the relationship between the image distance and the object distance for plane mirrors?

ACTIVITY

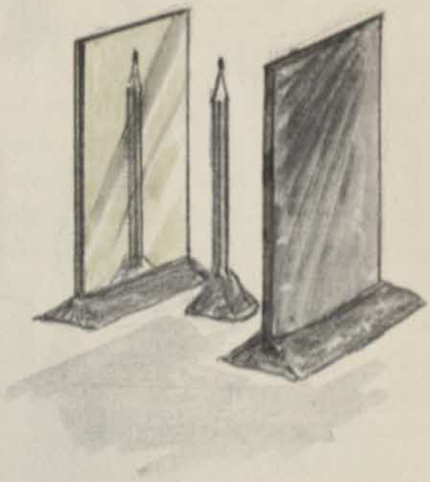
Stand in front of a plane mirror and raise your right hand. Look carefully at your image in the mirror. Which hand is raised by your mirror image? Are you sure that you are raising your right hand? Try raising your left hand. Now what does your mirror image do? Do you remember

what kind of a path the light energy follows as it travels from one place to another? What happens to the light reflected from you when it strikes the plane mirror? Can you explain why the image is reversed in a plane mirror? □□

Up until now your activities have involved working with a single plane mirror. Let's try some activities using more than one mirror at a time, and see if you can find out some more about the reflection of light waves.

EXPLAIN

Stand two mirrors up on your desk, parallel to each other, and about four inches apart. You can use clay or blocks of wood to keep the mirrors in an upright position. Place a pencil or some other small object between the mirrors. Look over one mirror at the image formed. What do you observe? How would you explain this?



PREDICT

Using cellophane tape, fasten the edges of two mirrors together and stand the mirrors upright on your desk so that they form a right angle. Obtain a watch or a small alarm clock to place between the two mirrors. Before you actually try it, predict the kind of image you think will be formed. What kind of an image is actually formed? Can you explain why this happens? What happens to the image when you make the angle between the mirrors greater than 90°? Less than 90°? Can you explain what you observe?

COMPARE

Why don't you see yourself as others see you when you look into a single plane mirror? Arrange the two mirrors from the previous activity at right angles to each other. Take a good look at yourself. How does this image differ from what you usually see in the mirror?

Have you ever amused yourself by looking through a kaleidoscope? Do you know now how a kaleidoscope works?

EXPLORE

Fasten three plane mirrors together so that they form a triangle. The inside of the triangle is now a three-sided mirror. Place some tiny pieces of colored paper, yarn, or beads on a piece of glass suspended between two books on your desk. Now stand your three-sided mirror on the glass directly above the colored pieces of material. What do you observe? What happens when you rotate your three-sided mirror? Why do you suppose a piece of glass was suspended above your desk? Would you get the same results if the colored pieces of material were placed directly on the top of your desk? Try it and see for yourself. Can you now give a more complete and accurate description of how a kaleidoscope works? □□

You have seen in the preceding activities that light energy may be either reflected, absorbed, or transmitted when it strikes a surface.

Most of your efforts were focused on the reflection of light waves. In the next section you will discover other things about light.

What Happens to Light When It Passes from One Substance to Another?

From your observations of a narrow beam of light, during your work on reflection, you have probably come to the conclusion that light travels in straight lines. But does it always travel in straight lines? Try the next three activities and see if you will still accept this statement as it stands. Maybe you will want to change or modify it in some way.

OBSERVE

Place about three or four drops of milk into a glass of water. Then, in a darkened room, shine a narrow beam of light straight down into the milky water. Can you see the light beam in the water? Can you see the same beam in air? If you can't see the beam too well, place some chalkdust or smoke in the air above the surface of the water. Now shine your ray of light so that it passes from the air into the milky water at

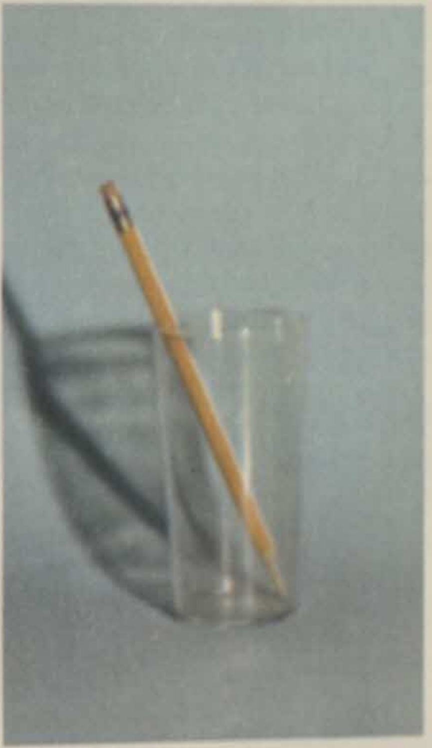
an angle less than 90°. What happens to the light as it passes from the air into the water?

EXPLAIN

Place a coin on the bottom of an empty cup. Look at the coin and then move your head backward until you can't see the coin any more. Keep your head in a position where the coin first completely disappears. Let one of your classmates slowly pour water into the cup, making sure that he doesn't move the coin. What do you observe happening as the water is poured into the cup? What explanation can you give for the apparent movement of the coin?

ACTIVITY

Place your pencil or ruler into a glass about three-quarters filled with water. Look at the pencil through the side of the glass. Do you notice anything unusual about it? Is the pencil really bent? Could the light be bending? What happens when you look at a pencil placed in a glass



without the water? Can you explain the difference in your observations? □□

The Bending of Light

The bending of a light beam as it passes from one medium (air) to another of different density (water) is called *refraction*. Do you know what causes this bending? Does the behavior of sound provide any clues? Sound energy travels 4 times faster in water than it does in air. It travels 11 times faster in steel than it does in air.

Does light have a speed? Could the speed of light energy be a cause of this bending of a light beam? What happens to a wagon if the front wheel hits a soft shoulder of the road? Can you walk as fast in sand as you can on a sidewalk? A light beam acts this way when it strikes a medium of different density. You will need more information before you can completely explain the bending of light. But the light beam does bend. Many times our experiences and observations run ahead of the explanations. As you explore light further, you will be able to explain much more about its behavior.

How Are Different Colors Produced from White Light?

In order to answer this question, you must be able to answer the two major questions: (1) What happens to light when it strikes something? and (2) What happens to light when it passes from one substance to another? In addition to being able to answer these two questions you will also need to understand something about the composition of *white* light.

For many of the following activities you will need a clear glass or plastic prism.

OBSERVE

In a darkened room, allow a narrow beam of sunlight to pass through one face of your prism at an angle less than 90°. Place a sheet of white paper on the opposite side of the prism. What do you observe reflected from the sheet of paper? You may have to turn the prism slowly as the light beam shines upon it. What can you now say about the composition of white light? Sunlight produces the best results in this activity. If it is not a sunny day you may shine other narrow beams of

light through your prism. You may want to try a flashlight or filmstrip projector. What happens each time?

COMPARE

Repeat this activity, only this time use a sheet of red construction paper instead of a sheet of white paper. What do you see produced on the red paper? Is this the same result as in the previous activity? Try the same activity again using a blue piece of paper, a green piece of paper, and other colored papers. What do you observe in each case? Can you explain your observations? □□

Sir Isaac Newton, a brilliant scientist who lived in the seventeenth century, felt that white light is composed of a series of different colors. This band of colors is called the *visible spectrum.* Do your observations support the view that light is made up of a series of colors?

Follow the same procedure for making the rainbow, only this time place a large magnifying glass between the prism and a sheet of white paper. Move the magnifying glass and the sheet of paper until the light passing through the prism is brought together on the paper in a small visible spot. What color is the spot of light? How does this activity support the view that white light is composed of different colors?

A World of Color

What a wonderful colorful world we live in. Just think for a moment how lucky most of us are to live in a world filled with color. The colors of flowers and birds are sights we should always remember to look for. Think for a moment about color. Think about the dark green of a leaf, the red of a rose, the orange of a setting sun. Consider just for a moment the yellow of a new born chick, the blue of the sky, and the deep purple of a violet. You can probably give hundreds of examples of rich colors, gentle colors and colors that have changed your moods. According to Newton, and most scientists

today, color is light: white light is a mixture of colors. All color can be explained in terms of light. In the next few activities you will explore more about this idea.

EXPLORE

Place a sheet of red transparent cellophane or glass between the prism and the sheet of white paper. Allow a beam of light to pass through the prism as you did before. What portion of the visible spectrum is transmitted by the red cellophane paper? What portions are absorbed? What happens when you use transparent materials of blue, green, and other colors? When working with transparent cellophane, you may obtain better results by using 3 or 4 pieces of the paper back to back, rather than one single sheet. What do you suppose this activity shows?

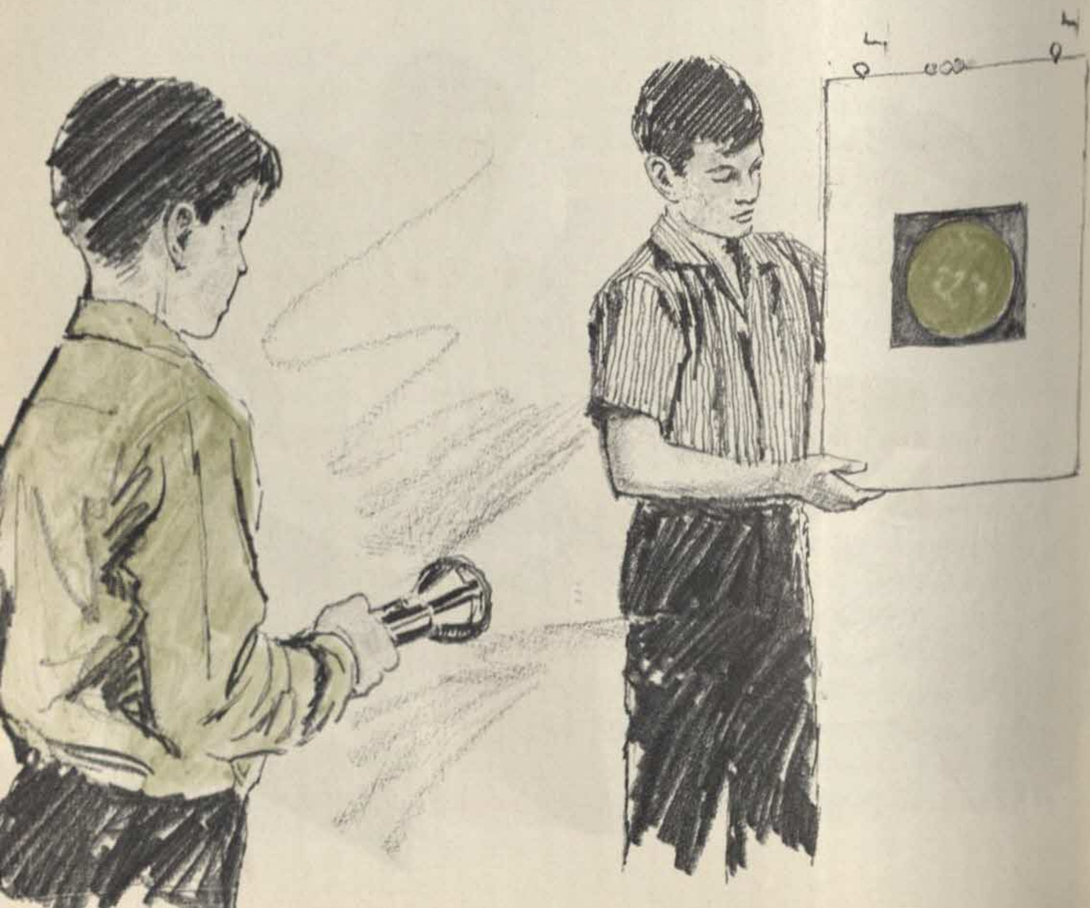
OBSERVE

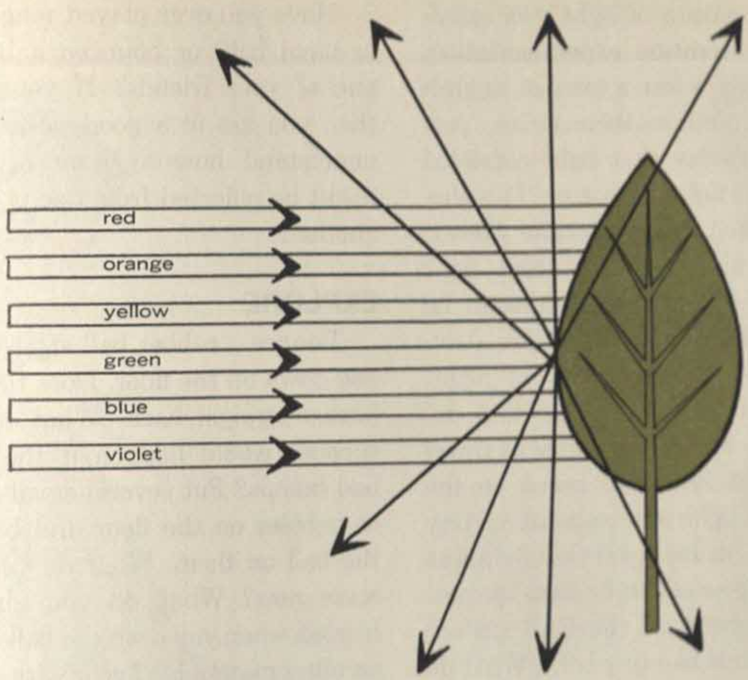
In a darkened room, experiment with beams of light produced by a filmstrip projector or flashlight. Cover each light source with different colored transparent cellophane so that different colored beams of light are produced. (Remember—several thicknesses are better than one.) Project the beams of light on a movie screen or sheet of white paper. What happens when you

shine a beam of orange light directly on top of a beam of green light? What colors are produced when you combine different colored beams of light on the screen? Can you produce a spot of white light by combining the colored beams that you are using?

ACTIVITY

Paste a square piece of bright red construction paper on a slightly larger sheet of white paper. In the center of the red paper paste a circular piece of bright green construction paper. Hang your arrangement up on the wall. In a darkened room, shine a beam of red light on the arrangement. What color does the outside border appear in red light? What color do you see in the inside square? What color is the circle in the center? Why do you think this happens? Can you explain what you observe when you shine a blue light on the arrangement? What happens when a green light shines on the hanging paper? What would happen if a red colored light shone upon a surface that *absorbs* red? What color would that surface appear? What colored surface absorbs red? Would you expect the same thing to be true if blue light shone on a surface that





absorbs blue? What colored surface absorbs blue light? Do you think this is true of other objects and other colors? □□

Do you understand why the *white* light of the sun makes an apple appear red? Which color is *reflected* to your eye by the apple? Which colors are absorbed?

Scientists are almost certain that energy cannot be created or destroyed. When some of the white light is absorbed by the skin of the apple (such as the green and blue light), do you know what happens to it? Remember your experiment with the black and white cloth! Why did the black cloth get hotter than the white cloth when exposed to the sun's rays? Which cloth reflected most of the light? Which cloth absorbed most of the light? Into what kind of energy was the light energy changed?

The Nature of Light: Wave or Particle?

What light is has puzzled man for centuries. Even today, scientists are not sure that the way in which they explain light is correct. Research on the nature of light continues, and perhaps some day we will feel more sure of our explanations.

Early philosophers and scientists knew a few things about the properties of light. Most of these things, however, were based on observations similar to yours. It was not until the middle of the seventeenth century

that the nature of light was examined by scientific experimentation. Sir Isaac Newton, a famous English physicist and mathematician, proposed a theory that light consisted of tiny particles of matter. This theory is called the *corpuscular theory*. Newton also suspected that light might be a wave and, although he had evidence for this too, he abandoned his wave model of light. Newton believed that the best explanation for light's ability to travel in straight lines was based on the idea that light was made up of tiny particles. Sir Isaac felt that light was reflected by a mirror because the particles bounced off the hard surface of the mirror like tiny balls. What do you think?

Sir Isaac Newton

Have you ever played ping pong or hand ball, or bounced a ball to one of your friends? If you have, then you are in a good position to understand how a beam of light might be reflected from one place to another.

EXPLORE

Bounce a rubber ball straight up and down on the floor. Does the ball bounce straight back? What do you suppose would happen if the floor had bumps? Put several small rocks or pebbles on the floor and bounce the ball on them. What do you observe now? What do you observe happen when you drop the ball down on other materials? Try it with a soft pillow or your jacket. Try it with a pan of water and with other substances. How does the condition of the floor's surface affect the bouncing ball?

ACTIVITY

Bounce a ball off the floor to one of your classmates. Throw the ball so that it strikes the smooth surface of the floor at different angles. The angle that the ball's path makes with a perpendicular line to the floor, at the point of impact, can be called the *angle of incidence*. The angle that the path of the ball makes with this same line, as it bounces toward your classmate, can be called the *angle of reflection*. What happens to the way the ball bounces toward your friend as you change

the angle with which the ball strikes the floor? What happens to the angle of reflection as you change the angle of incidence? What do you notice about the angle of incidence and the angle of reflection? What did you learn about the angle of incidence and the angle of reflection in a reflected light beam? Could light be something like a tiny bouncing ball? □□

At about the same time that Newton was proposing the particle theory of light, a Dutch physicist and astronomer, Christian Huyghens (HI-genz), suggested an opposing explanation of the nature of light. Huyghens' theory was called the *wave theory*. This theory stated that light consisted of tiny waves. Huyghens felt that if light traveled as tiny waves, two beams of light could cross

What happens when two beams of light cross?

each other easily. If light consisted of tiny particles they would surely collide if two beams of light were shined into each other.

OBSERVE

Take two flashlights and shine their beams across each other in a dark room. Use chalk dust to make the beams more visible. Carefully look at the "area of collision." Do you observe any evidence of light being deflected from its course? What evidence is there of particles bouncing? Which theory of light would you support at this point? □□

Huygens' theory also nicely explained another problem which the particle theory could not answer. It had to do with light passing through a prism and being broken up into the colors of the rainbow. If light were a particle, there would be no explanation for this. But if light were made of waves, then this could be explained by saying that each color had its own wave length. Light of

Christian Huygens

different wave lengths could be bent differently as it passed through the prism. In this way, the prism is able to separate the colors that make up white light.

But the wave theory also had some rather serious flaws. If light was a series of tiny waves, there would be no reason why it couldn't go around corners, as water and sound waves do. Yet observations of shadows proved that light could not do this. The theory could not explain the two most elementary facts about light: that it traveled in straight lines and that it produced sharp shadows. Another serious flaw in the wave theory can be seen if a vacuum jar is available.

ACTIVITY

If a motor driven vacuum pump is available, your teacher will evacuate the air from a bell jar or some other glass container. Shine a light through the glass container. Can the light be seen on both sides of the container? Can it be seen inside the container? □□

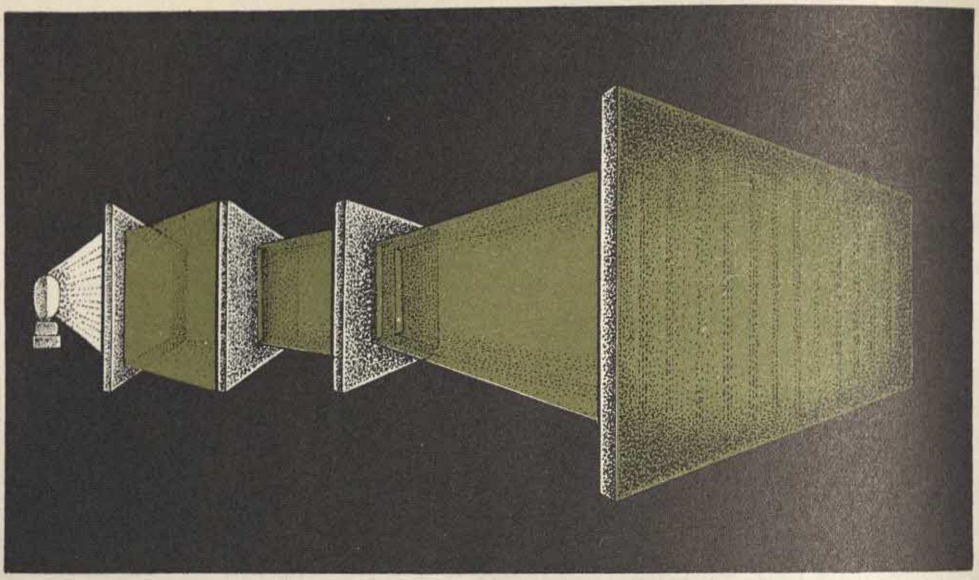
Up to this point it was believed that waves needed something to travel through. This something is called the *medium* for the wave. Observations similar to the ones made of light passing through a vacuum are extremely damaging to the wave theory. For it was felt that most of the space between the sun, the other stars, and the earth was a vacuum.

If light were a wave, the scientists reasoned, it could not possibly travel through outer space. All of the known waves travelled through a medium. A water wave has water for a medium. A rope wave travels through the rope. Waves need a medium through which to travel. There would be no medium for the light waves to travel through, and that was an absolute necessity for wave motion.

Most of the scientists of the seventeenth and eighteenth centuries accepted Newton's theory. Questions about light were raised which could not be answered by particle theory. But it seemed more logical to most scientists than the wave theory. And if that were not enough, the great name of Sir Isaac Newton was behind it. This situation persisted until the early 1800's, when some new discoveries strongly supported the wave theory. A very important experiment was done by an English physician and physicist, Thomas Young. If you have a carbon arc lamp available, you can try his experiment yourself.

ACTIVITY

Using a razor blade, cut two narrow slits about an inch long in a piece of opaque aluminum foil. Fasten this foil over a 3" square opening in a piece of black cardboard. The slits should be as close together as you can get them. (Preferably not more than 1/16" apart.) Shine a narrow band of light from a carbon-arc lamp through the slits from about two yards away. Focus the light passing through the slits on a piece of dull white, non-reflecting cardboard. Look carefully at the light image formed on the cardboard. What do you observe? □□



When Thomas Young did this experiment in 1801, he observed a series of bands of light separated from each other by areas of darkness. This observation could not be explained by the corpuscular theory of light. For if light were a stream of particles, the two beams, after passing through the narrow slits, would merely appear brighter where they overlapped and appear dimmer where they did not. Only the wave theory could explain the light and dark bands of light.

Through the nineteenth century, the wave theory was widely accepted as being the best explanation of the nature of light. But early in the twentieth century, the work of Max Planck, a German physicist, and Albert Einstein, a German-born physicist, who spent most of his life working in the United States, led to a new theory of light. In many ways this new theory was a successful "marriage" of Newton's corpuscular theory and Huygens' wave theory. A new kind of particle was suggested which behaved both as a particle and as a wave. This new particle was given the name *photon* (FOH-tahn). This new theory remains today as our best way of explaining the nature of light. It is often referred to as the wave-particle theory. You can be fairly sure, however, that new and "better" theories will be forthcoming. Perhaps you or one of your classmates will have a hand in their development.

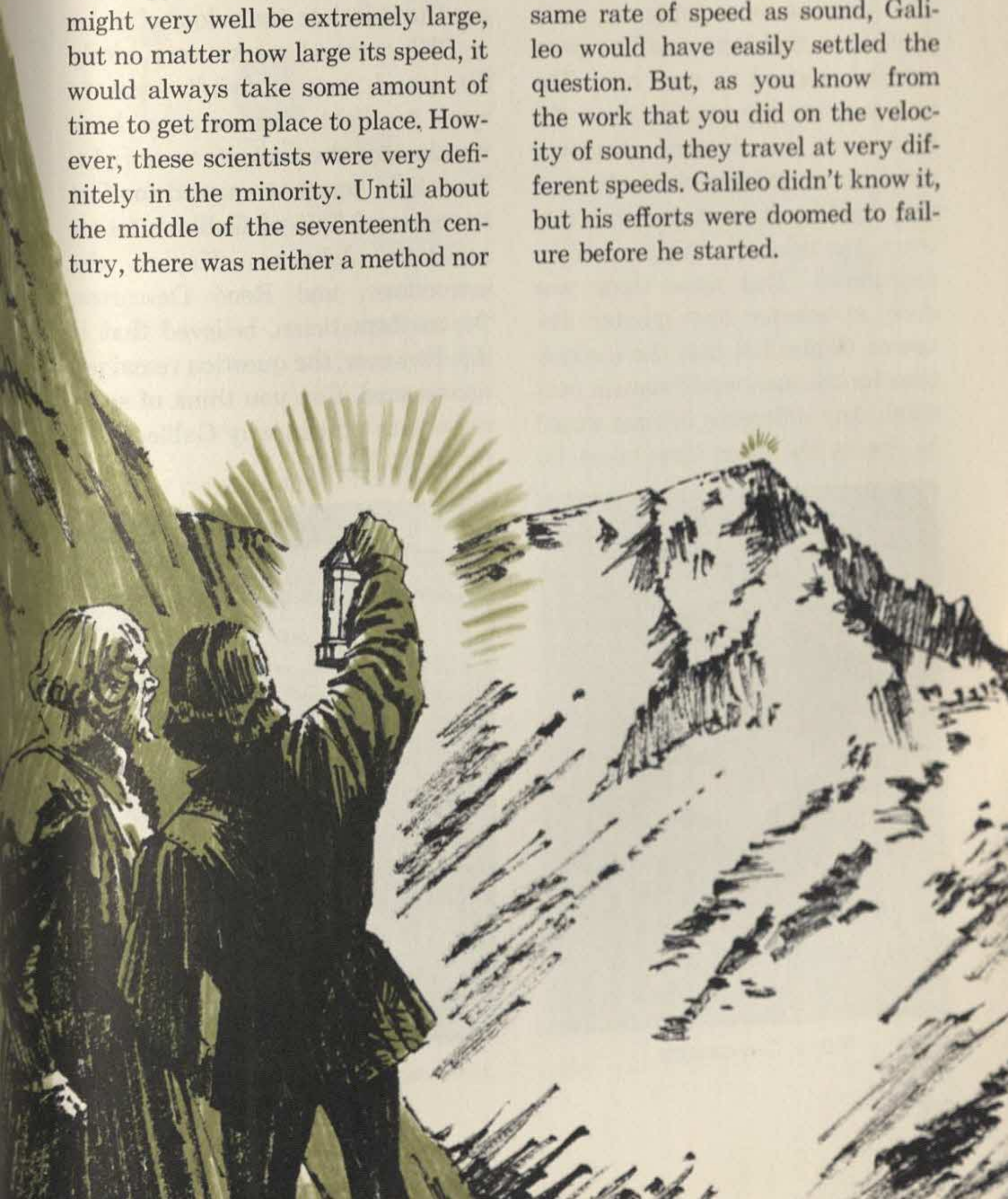
The Speed of Light

The question as to how fast light travels from one place to another has concerned man for centuries. Almost all of the ancient philosophers felt

that light traveled so fast that it took absolutely no time to go from place to place.

Everything that man was able to observe seemed to indicate that this notion about the speed of light was correct. Later, there were scientists who suggested that the speed of light might very well be extremely large, but no matter how large its speed, it would always take some amount of time to get from place to place. However, these scientists were very definitely in the minority. Until about the middle of the seventeenth century, there was neither a method nor an instrument for determining the speed of light. It was not until 200 years later that such a method and a sensitive instrument were perfected.

The first attempt to actually measure the speed of light was made by the Italian genius, Galileo Galilei. If light traveled at about the same rate of speed as sound, Galileo would have easily settled the question. But, as you know from the work that you did on the velocity of sound, they travel at very different speeds. Galileo didn't know it, but his efforts were doomed to failure before he started.



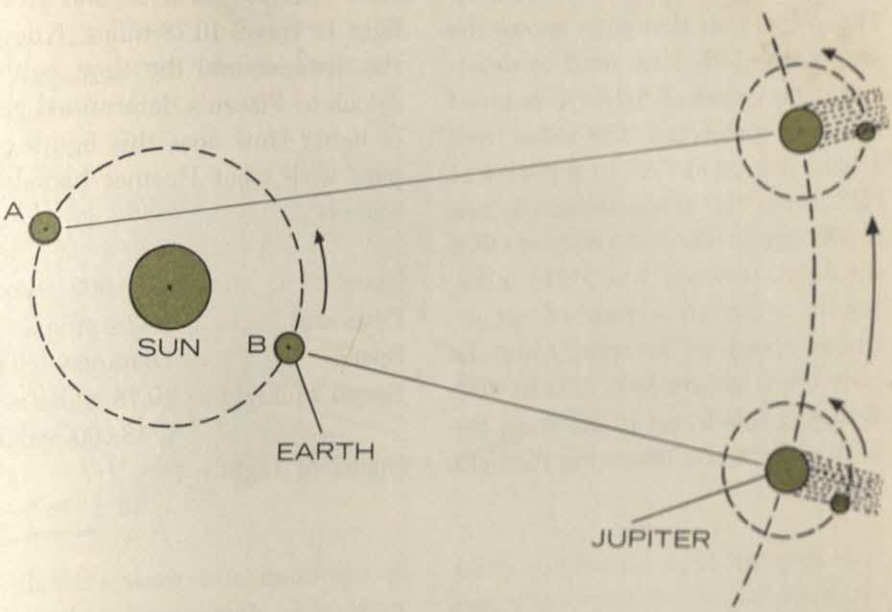
The speed of sound was experimentally determined in the early seventeenth century by a French physicist, Father Marin Mersenne. In 1638, Galileo tried to do the same for the speed of light. His procedure was a simple one. Two men with lanterns stood a known distance apart. The lanterns were equipped with shutters so that light could be given out and stopped by each man. The plan was for one man to show the light from his lantern. Knowing the distance and measuring the time that light took to travel that distance, the velocity of light could be determined. This same thing was done at greater and greater distances. Galileo felt that the reaction time for the men would remain constant. Any difference in time would be due to the extra time taken by the light to travel the greater distance. Galileo knew the distance between the lanterns. He also planned to measure the time. How do you suppose he planned to find the velocity of light? Do you remember how you measured the velocity of sound? What information did you need to calculate the velocity?

This method works very nicely for sound, but it didn't seem to work for light. Galileo must have wondered if the ancients were right. Does light travel at a speed too fast to measure? Two of Galileo's fellow scientists, Johannes Kepler, the astronomer, and René Descartes, the mathematician, believed that it did. However, the question remained unanswered. Can you think of some reasons to explain why Galileo's experiment failed?

René Descartes

Johannes Kepler

Light takes 1,000 seconds to travel across the diameter of the earth's orbit, which is about 186,000,000 miles.



Roemer noticed that one of Jupiters' moons came into view 16 minutes later at position A than it did when earth was at position B.

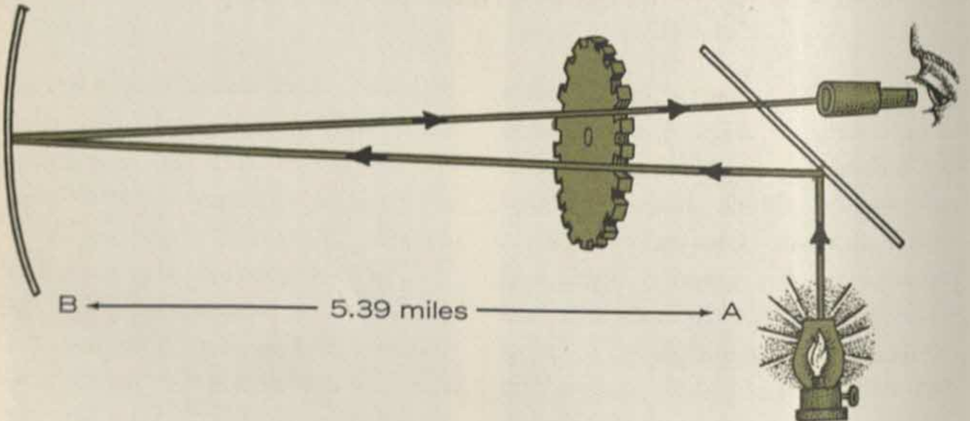
About 30 years after Galileo's experiment, in 1676, the first real breakthrough occurred. A Danish astronomer, Olaus Roemer (RUH-mur), announced to the world that he believed the speed of light had a limited value. He not only announced this, but supported his position with a set of observations which had been made not only by himself, but by other astronomers. The facts that Roemer made use of were known by other scientists. They were puzzled by these facts, and had been unable to explain them. Roemer's outstanding contribution came from his ability to look at these facts in a new way and to put the information together to arrive at a definite figure for the speed of light.

The information that Roemer made use of is shown in the illustrations on this page. Can you put this information together and calculate the speed of light that Roemer arrived at?

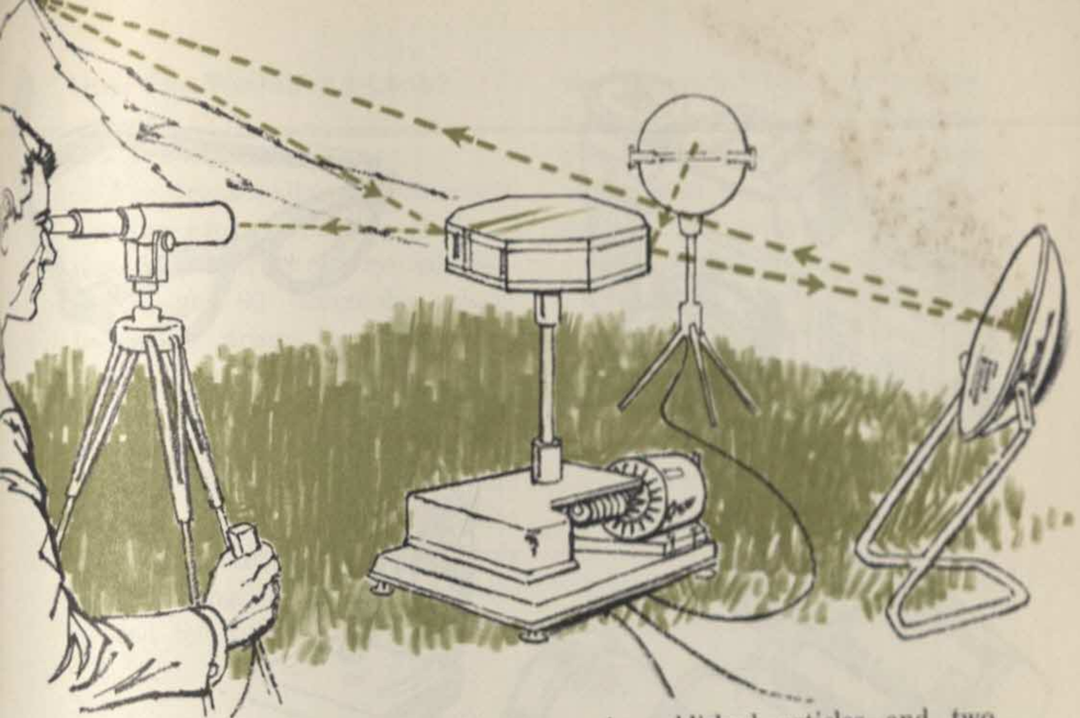
It was not until 1729, more than fifty years later, that Roemer's position was completely accepted by other scientists.

In 1849 the French physicist, Armand Fizeau, measured the speed of light on the surface of the earth. The picture on this page shows the arrangement that he used to determine the speed of light. A beam of light was projected 5.39 miles from a light source at "A" to a mirror at "B". From "B" it was reflected back to "A" again. The total distance that the light traveled was 10.78 miles. Fizeau inserted a toothed wheel, whose speed of rotation could be controlled, in between "A" and "B". By using this wheel to interrupt the path of light and observing the light reflected back when it appeared brightest, Fizeau calculated that it took 1/18,000 of a second for the light to travel 10.78 miles. Knowing the distance and the time, can you calculate Fizeau's determined speed of light? How does this figure compare with what Roemer had determined?

Time	= 1/18,000 second
Distance	= 10.78 miles
Speed	= Distance ÷ Time
Speed of Light	= 10.78 miles ÷ 1/18,000 second
Speed of Light	= ?



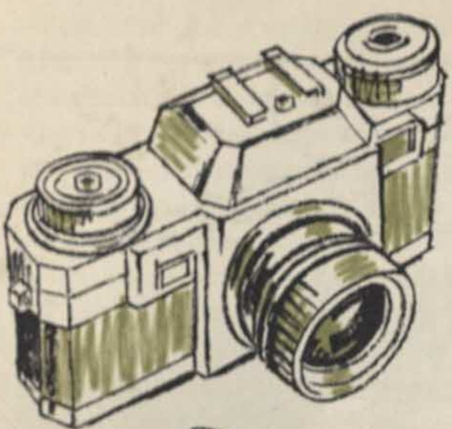
How would you calculate the speed of light using Fizeau's data?

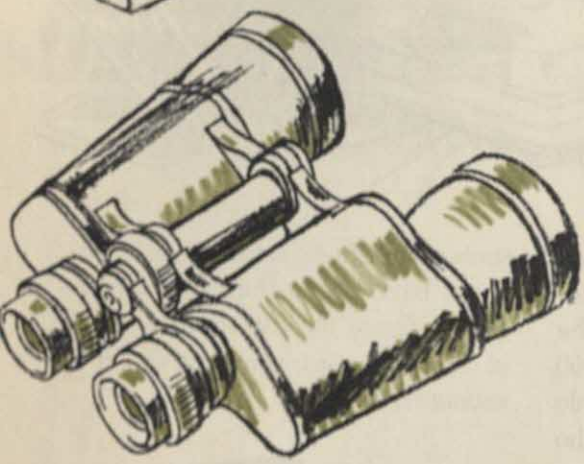


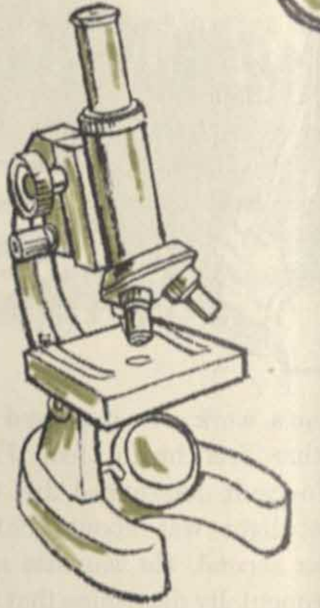
Fizeau's work was improved on by another Frenchman, Jean Foucault. Foucault determined that the speed of light was about 185,000 miles per second. He was also able to experimentally determine that the speed of light was less in water than it was in air.

In 1878, a young ensign in the United States Navy, who was an instructor in physics and chemistry at Annapolis, had his first statement on the speed of light published in the *American Journal of Science.* It was a letter to the editor entitled, "On a Method of Measuring the Velocity of Light." And thus began a professional career which was to result in America's first Nobel Prize in science. Albert A. Michelson (1852-1931) devoted his lifetime to a study of light and optics. Michelson's published articles and two books have led to the presently accepted figure for the speed of light of 186,291 miles per second (in a vacuum).

Albert Michelson







Lights, Lenses, and Optical Instruments

We now know that light is energy in the form of a wave that is emitted from its source in short bursts called photons. Thus light can behave as a wave or as a particle. We also know that light can be transmitted, absorbed, reflected, and refracted. Now we are ready to use our knowledge of light to construct and understand some of the many wonderful optical instruments used by man in his daily life.

How are light waves affected by different kinds of lenses? How can we use our knowledge of light and lenses in photography? How can scientific instruments make use of lenses and light waves to improve and extend man's powers of observation? The questions which could be asked are many. Let's stop, however, with these three and begin to see if you can not only discover answers for them, but also raise other questions for yourself.

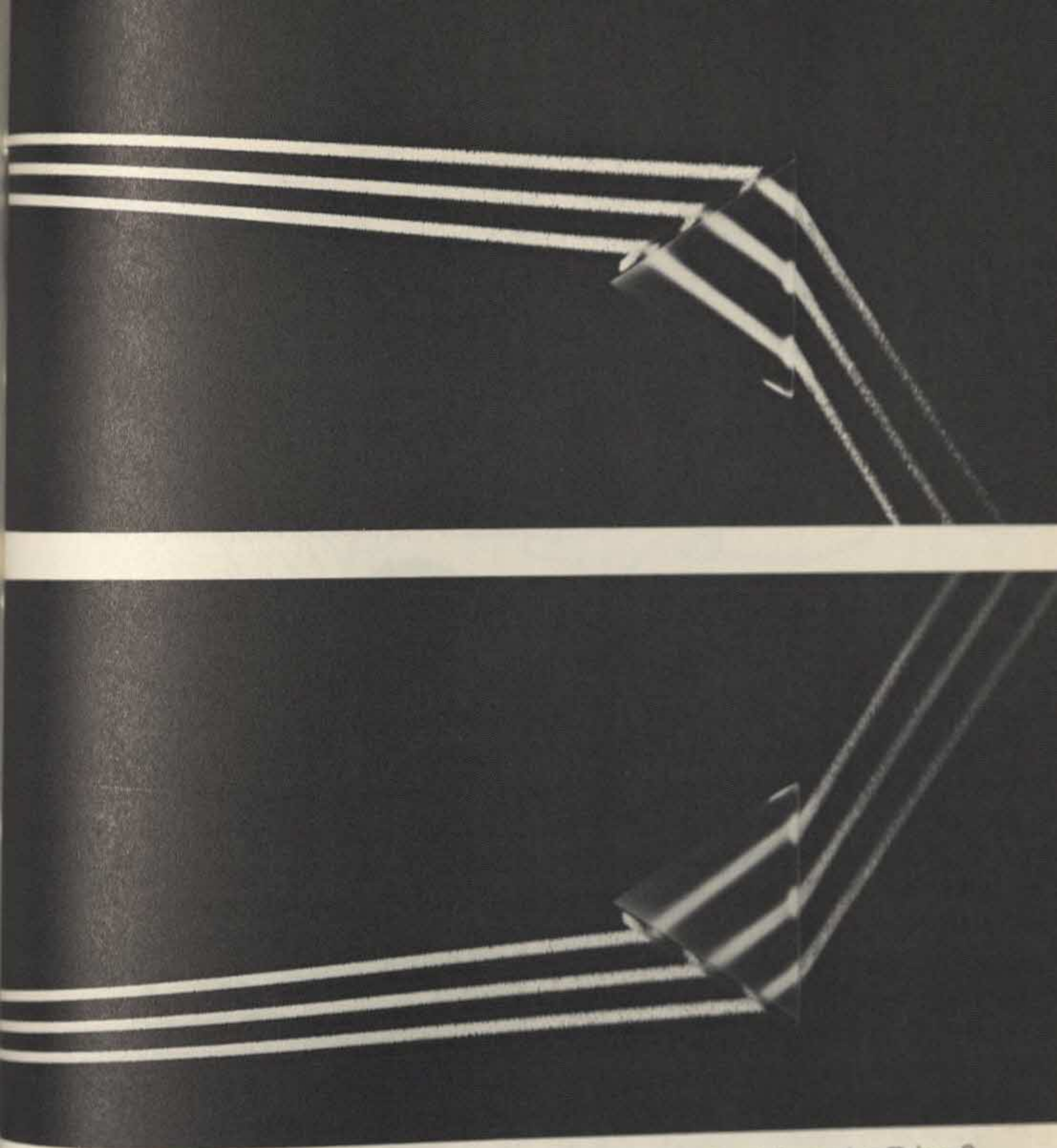
How Can We Make a Lens?

ACTIVITY

For this activity you will need a filmstrip projector, a strip of aluminum foil, 2 strips of pure red cellophane, two 60° triangular prisms, two other prisms, and a piece of white paper.

Place the aluminum foil over the projector lens so that no light comes through. Then take a needle and make a hole near the top of the lens. Hold one piece of red cellophane over this opening. What colors are absorbed by the red cellophane over this opening? What color is transmitted? Now hold a 60° triangular prism so that the base is horizontal, and permits the red beam to enter the triangular prism through a side and a short distance from the top, as shown. What happens to the beam as it leaves the prism? Use chalk dust to make the beam visible in the air. What happens if the cellophane is removed? What name do we give to this bending of light? What name do we give to the spreading out of the different colors of white light? Do you know why we are using red cellophane instead of white light?

Now place the two 60° prisms base to base horizontally. With the needle, make another hole in the aluminum foil at the bottom of the lens. Place one piece of red cellophane over the top hole and the other piece of red cellophane over the bottom hole. Arrange the prisms so that the two rays of red light enter the different prisms at about the same relative positions. Observe where the two beams meet. Measure the distance from the center of the prisms to this point with a ruler. This distance is called the *focal length* of the *lens* you have just made. What does this lens do to light beams that enter it? Is this lens thicker at the center than at the edge? Why do they call such lenses *convex* lenses? Why do they say that *convex* lenses are *converging* lenses?



What happens to light when it passes through a triangular Prism?

Repeat this experiment using the other two similar prisms. What is different about the focal length? When is the focal length greater? If a convex lens is thicker at the center, does the focal length become greater or smaller?

Can you suggest what would happen if we repeated the same activity but turned our prisms point to point instead of base to base? Try it! You have now made a *concave* lens. Why do they call concave lenses diverging lenses? Can you think how you would make use of both types of lenses? What do you

think would happen if we put two similar lenses together, one convex, and the other concave? Why?

You have probably seen a magnifying glass used to focus the sun's rays on a sheet of paper. Of course you know what happens. But, to begin our study of light and lenses, try this simple activity once more and see if you can explain what happens in more detail than you could before you began your work on light in this unit.

MEASURE

Examine the lens of the magnifying glass. Is it convex or concave? Should it bring the rays to a focus? On a bright sunny day hold a magnifying glass about one foot above a sheet of paper. Do you notice anything different about the area underneath the magnifying glass when you compare it to the rest of the paper? Move the magnifying glass slowly toward the sheet of paper. What do you observe happening? Do

this same thing again. Only this time, tilt the glass from side to side as you move it down toward the paper. What do you observe happening? Hold the magnifying glass in the position where the image of the sun is brightest for a minute. What is happening to the paper? What form of energy has the light been changed to? In this position, use a ruler to measure the distance between the magnifying glass and the paper. What is the *focal length* of the lens? Try the same activity with another magnifying glass. Compare their *focal lengths*. The focal length of a lens tells us very much about how we can use a lens. □□

Why is it extremely dangerous to look directly at the sun? Why is it even more dangerous to use a magnifying glass to look at the sun? Do you know how scientists protect their eyes when they look at the sun?

OBSERVE

In a darkened room, shine a narrow beam of light through the same magnifying glass that you used in the previous activity. Some chalk dust or smoke in the air, or in a small box containing small holes will enable you to make much better observations. What happens to the light beam after it passes through the magnifying glass? With the help of one of your classmates measure the distance from the lens to the point where the beam of light waves are focused. How does this measurement compare with the one in the

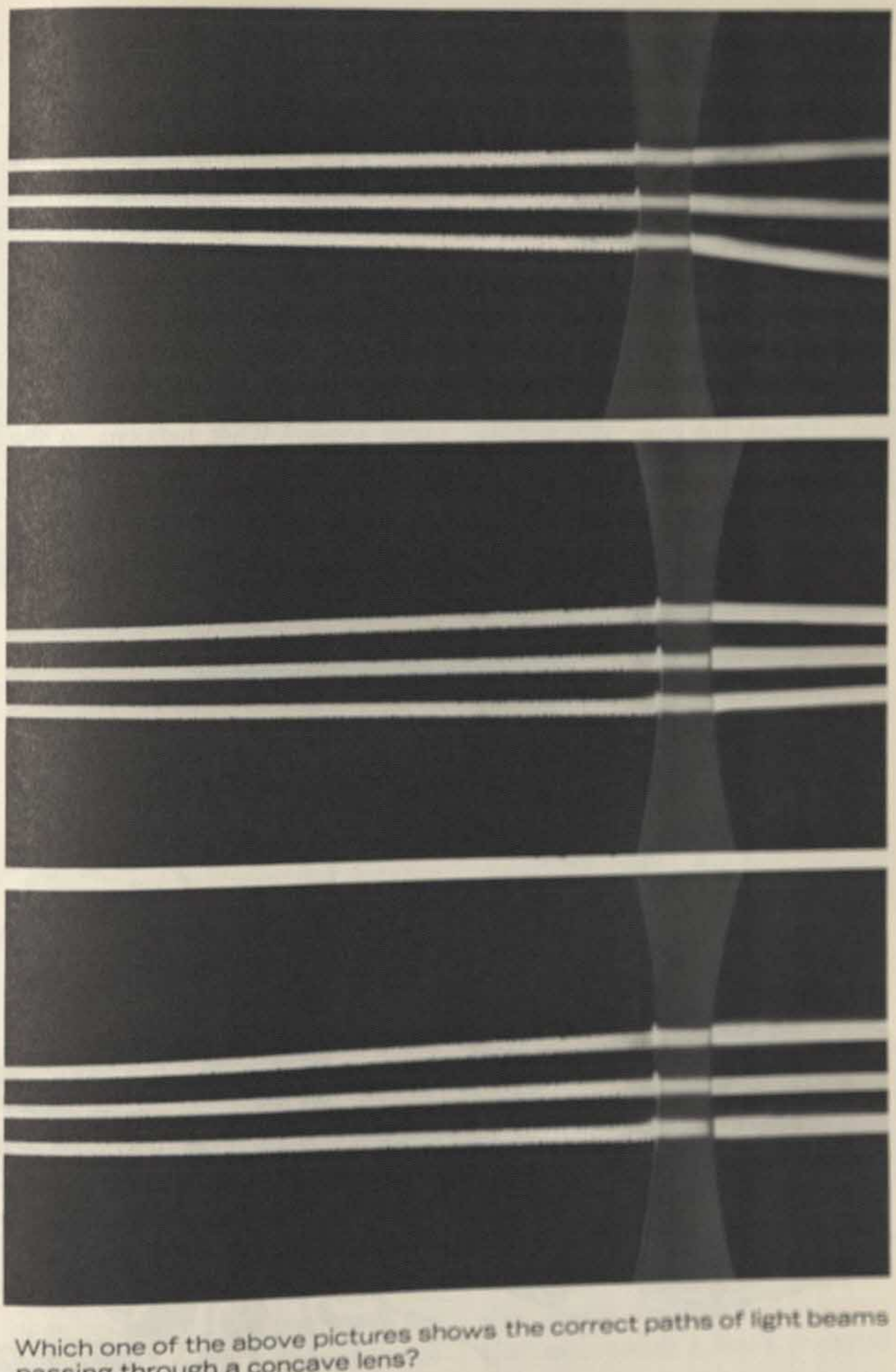
previous activity? How does the magnifying glass compare with a flat piece of transparent glass? What causes the light to behave as it does when it passes through a magnifying glass? Can you see any similarities between what you have been observing here and the refraction of light?

MEASURE

Hold the same magnifying glass above a page of printed material. Move it up and down until you reach the point where what you see through the glass is most clear and sharp. Measure the distance from the magnifying glass to the page. How does the distance compare with the measurements that you made in the previous two activities? In order for a convex lens to magnify, how must the distance to the paper compare with the focal length of the lens?

PREDICT

Can you predict what will happen when light is passed through a concave lens? In a darkened room, shine a narrow beam of light through a concave lens (Again—chalk dust or smoke will help.) What do you observe happening to the beam of light? Does it come together at a point, as it did with the convex lens? Does something else occur? Do you think that the shape of the lens has anything to do with what happens to the light passing through it? Can you explain what you observe happening? Was your prediction correct? How can you tell when a lens is a concave lens? How does this lens compare with the concave lens you made from the two prisms?

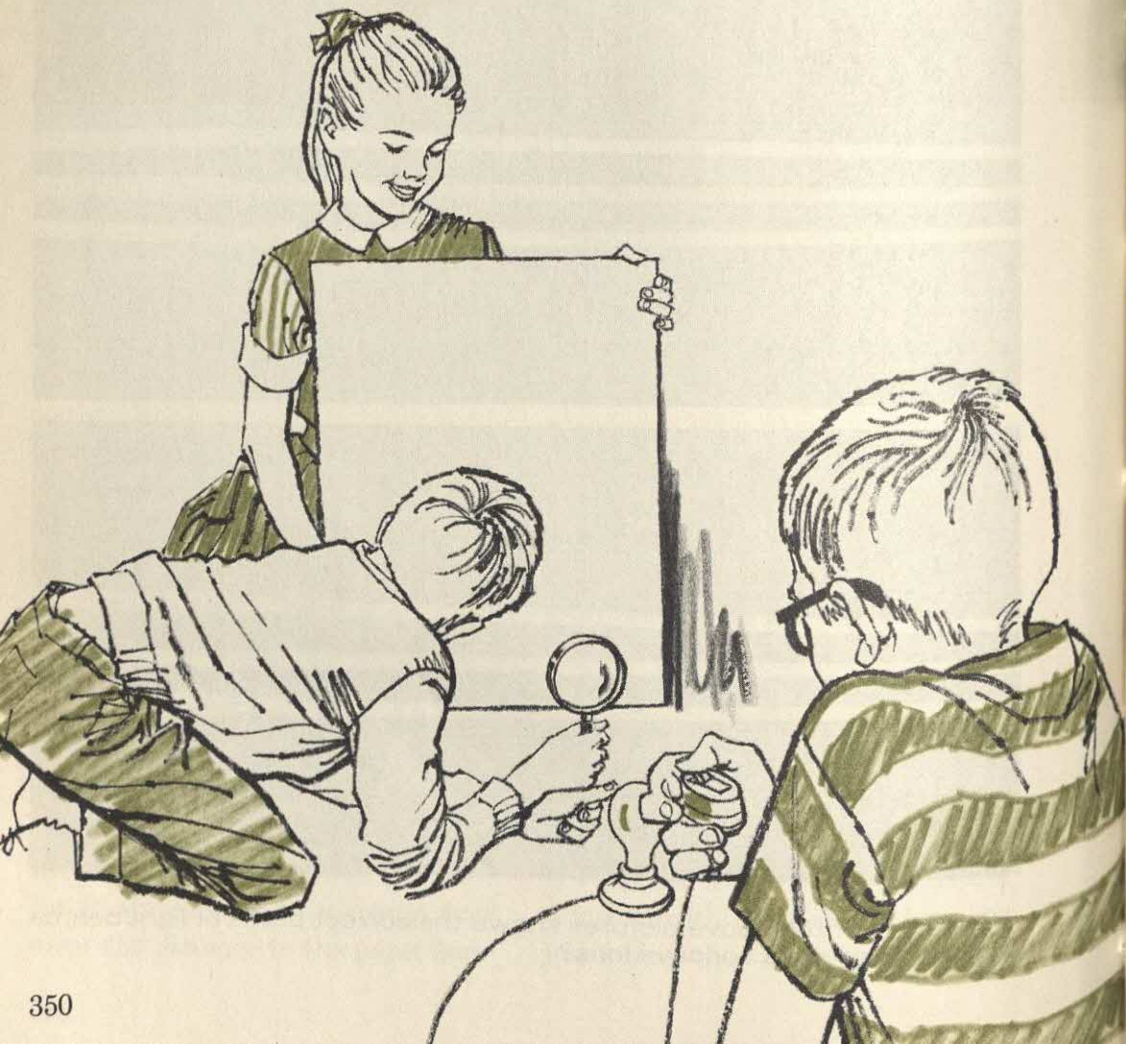


Which one of the above pictures shows the correct paths of light beams passing through a concave lens?

EXPLORE

For this activity you will need both a clear and a frosted 40-watt bulb in an electric socket with a long length of electric wire, a piece of white cardboard, a yardstick, your magnifying glass, and a 35 mm. Kodachrome slide. You will also need the assistance of two of your classmates. In a darkened room, place the cardboard about three feet from the lighted clear bulb. (Be careful not to touch the glass. Why?) Now place the magnifying glass between them and move the magnifying glass until the image of the thin wire in the electric light bulb is sharp and clear (you should be able to count the number of coils in this wire). How does the image of the wire differ from the image you normally get with a magnifying glass?

For how many positions of the lamp can you find a distance at which a sharp image will appear on your screen? What happens to the



size of your sharp image as the bulb approaches the lens? See if you can find a position of the bulb where the sharp image is twice the distance from the lens as the bulb is. In that position, measure the size of the image and compare it with the size of the bulb. Now put the bulb where the screen was and the screen where the bulb was. What do you notice?

How Can We Make a Slide Projector?

Turn the bulb off from the last activity and wait until it cools. Replace the clear bulb with the frosted bulb. Now find a position where the image of the bulb is four times as big as the bulb itself. Which will be closer to the lens, the bulb or the screen? What will the ratio of the screen distance to the bulb distance be? Measure it. Does it check? Now carefully place the Kodachrome slide about a half inch in front of the frosted bulb. Adjust the screen so as to get a sharp picture. What have you just made? What kind of lens is present in projectors? Look at your teacher's projector and see if this is true. Look at the numbers on the barrel of the projection lens and see if you can find its focal length. Why is it necessary to place the slide upside down in the projector? How can you get a larger projected

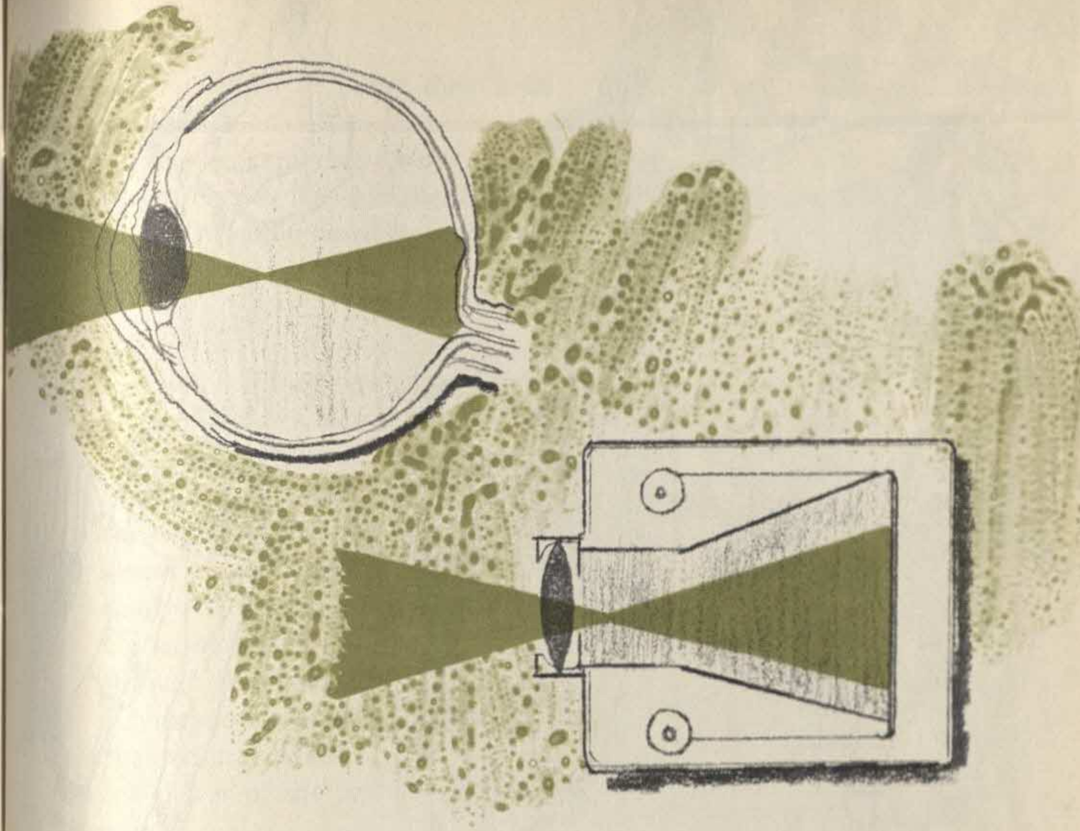
image on the screen? Do you think you can use this same device to make large pictures from small-sized negatives? What does the photographer call such a device?

The Camera

So far, we have taken a simple convex lens like a magnifying glass and found we were able to make a slide projector and photographic enlarger from it. Now let's see if we can use a convex lens to make a camera.

EXPLORE

Obtain a cardboard milk container. Rinse it thoroughly. Now cut off the container so that it is one inch deeper than the focal length of your magnifying glass (about four inches). Cut a round hole in the bottom of the container about the size of a dime. Take some aluminum foil or black paper and cover the sides and bottom except for the round opening at the bottom. Put some tissue paper on the other side of the container to serve as a screen. Shade



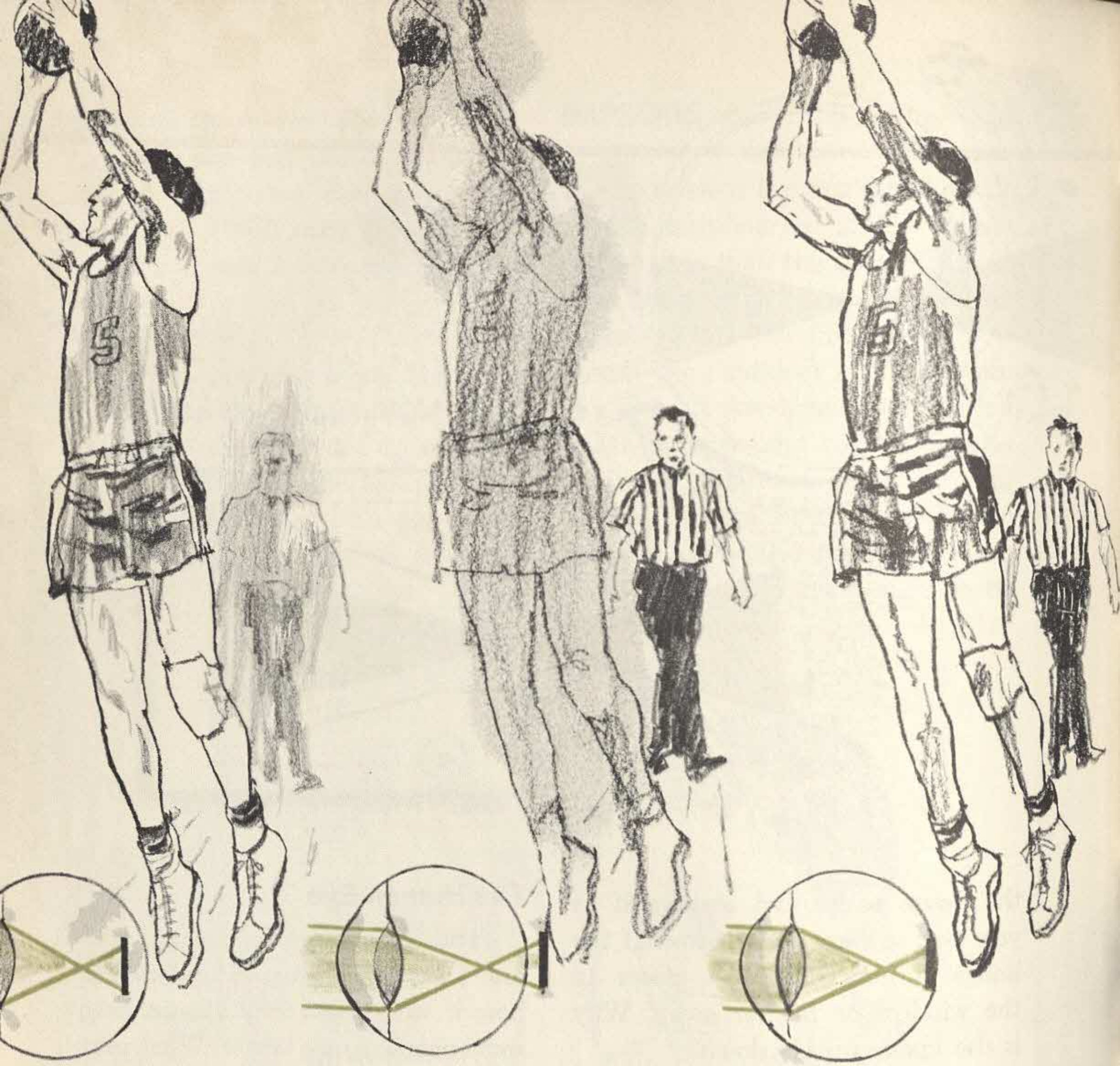
the tissue paper and observe it as you look toward the window. If the image is not sharp, get closer to the window or farther away. Why is the image upside down?

ACTIVITY

Repeat the previous activity. Only, this time, use a concave lens instead of a convex lens. What do you observe? Can you explain this? Does a line drawing of parallel light rays support your explanation? Can you suggest a method for determining what kinds of lenses are contained in a pair of eye glasses? To find out, work with boys and girls in your class who wear glasses.

The Human Eye

The human eye is like our camera. Let's see if we can understand how it works and why glasses help some people to see better. What part of the eye is like the film in the camera? What part is like the light-tight box? Where is the lens? What regulates the amount of light that enters the lens? You have seen that in good cameras the distance between the lens and the film is changed to make the image sharper. In the eye, the distance between the lens and the retina can't change. Why? How do you think the eye lens focuses a sharp image on the retina at almost any distance?



If a person is *nearsighted*, he can see things well that are *near*. However, he can't see distant objects clearly. The reason for that is that his eye lens is too convex for the length of his eyeball. Where will the image of distant objects fall? What kind of eyeglass lens will combine with the eye lens to make a combination that is less convex than the eye lens alone?

What is farsightedness? What is the condition of lens and eyeball? How is farsightedness corrected by glasses?

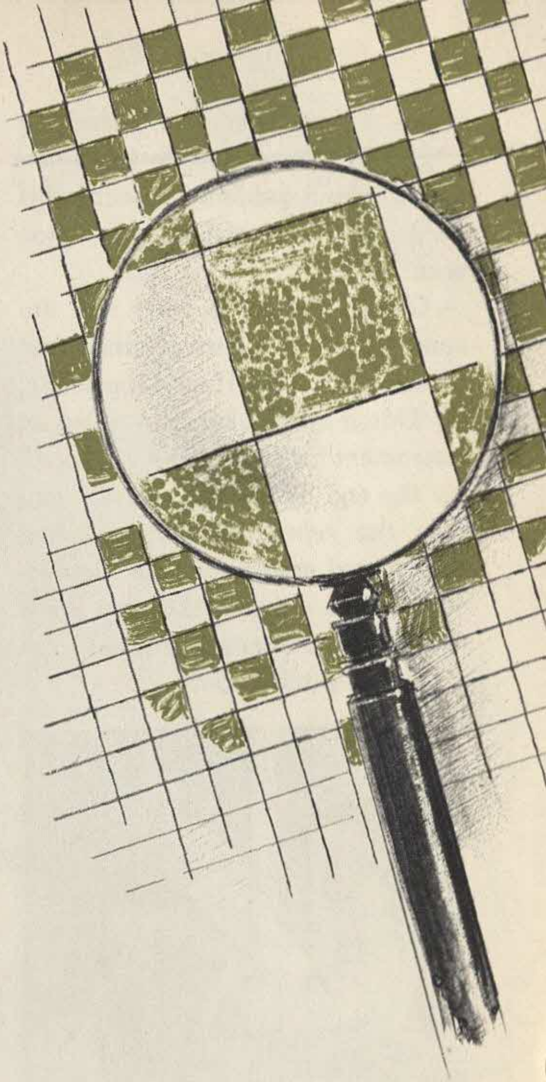
Roger Bacon, a British philosopher and scientist of the thirteenth century, is often given credit for inventing eyeglasses. But there is no way of really knowing when man first used glass lenses to help himself see things more clearly. Glass lenses have been found in tombs in Northern Africa which were sealed up in about the year 400 B.C. So man has known how to make mag-

nifying lenses for more than 2,300 years.

The magnifying power of a simple convex lens is rather limited. It can be determined by doing the following activity.

MEASURE

Hold a convex lens above a sheet of graph paper. Move the lens up and down until you find the point at which the lines that you see through the lens are sharpest and clearest. Now count the number of spaces that you see outside the lens corresponding to one space viewed through the lens. What is the magnifying power of the lens shown in the picture? What is the magnifying power of the lens that you are using?



Roger Bacon

Telescopes

Man's powers of observation can certainly be improved by using lenses. But perhaps things would have remained as they were in Roger Bacon's time, were it not for an accident which occurred in the year 1608. For it was in that year that a Dutch lens maker happened to hold up to a window two lenses that he had been working on. Instead of looking through each one separately as he usually did, he happened to

glance through them one behind the other. He was amazed to see a distant windmill suddenly appear in his front yard. And the telescope was born.

Galileo Galilei in Italy and Johann Kepler in Germany made refinements in what Hans Lippershey, the Dutch lens maker, had called an instrument for "seeing at a distance." By the end of the seventeenth century the *refracting telescope* had contributed greatly to man's knowledge of the universe. Do you know why the instrument is referred to as a refracting telescope?

Hans Lippershey

If a good refracting telescope is available, examine it carefully. Use it for making observations of distant objects on earth and for viewing the moon and other objects in the night sky. Of course, you should NEVER look directly at the sun through *any* telescope. Serious injury to your eyesight can result.

In the toy department of many stores, telescopes can be purchased very cheaply. They are not quality instruments, but are often useful in finding out more about light, lenses, and telescopes. You can also make your own refracting telescope by doing the following activity.

ACTIVITY

Either find or make two cardboard tubes, each about one foot long. Paper-towel tubes, mailing tubes, or tubes made out of heavy construction paper will be satisfactory. One tube should fit snugly inside of the other tube. But you should be able to slide the inner tube in and out easily. For your telescope you will need two convex lenses. One should have a focal length of about one inch, and the other a focal length of about nine inches. Do you now know how to check the focal length? Place the lens with the larger focal length in one end of the larger cardboard tube, and the lens with the smaller focal length in one end of the other tube. Each lens should fit tightly in place. This can be accomplished by wrapping tape

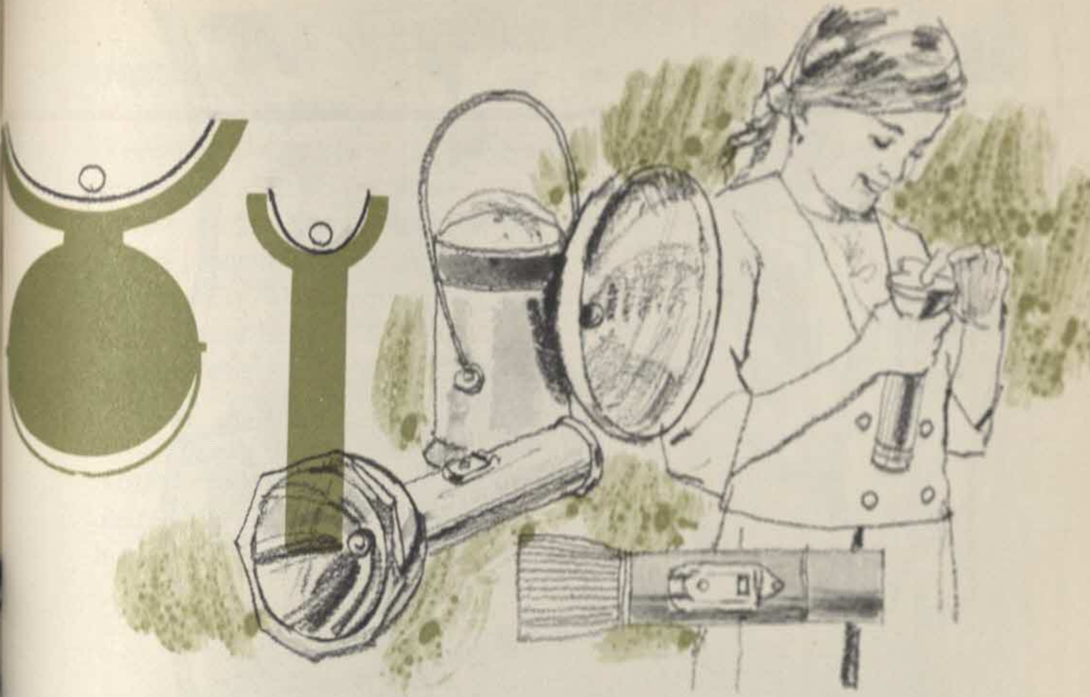
around the edge of each lens and then forcing it into position. Put the smaller tube inside of the larger tube. What do you see when you look through the *eyepiece lens?* (the smaller focal length lens—the other lens is called the *objective lens*). What do you observe happening as you move the smaller tube in and out? How does the focused image of a distant object look through your telescope? Can you draw a line diagram showing how an image is formed by your telescope? Follow the same procedure that you used earlier. Only this time, remember that two lenses are involved in the final image formation. □□

In the United States, interest in telescopes developed very slowly. It was not until 1847 that a satisfactory telescope was installed at the observatory at Harvard College. But soon observatories could be found at other colleges and universities. The 1847 telescope was as large and powerful as any which could be found in the world at that time. It had an objective lens which was fifteen inches in diameter and was called the "Great Refractor."

Interest in astronomy in the United States then led to the development of the world's largest refracting telescope. It was shown publicly at the Chicago World's Fair in 1893. The objective lens of this telescope was forty inches in diameter. Man could now see farther out into space than he had ever seen before. This telescope is still the largest refracting telescope in the world today. It is located at the Yerkes Observatory in Wisconsin.

The Great Refractor, located at Harvard College Observatory

The largest refracting telescope in the world, located at Yerkes Observatory



The purpose in making a large telescope is to gather as much light as possible. This makes it possible to see very distant stars, which are quite dim to the unaided eye.

It is difficult and expensive to make large telescopes by using lenses alone, and it is hard to avoid seeing an image that has a "rainbow" around it. The "rainbow effect" results because the lenses act the way the prisms did in your earlier activities. Some of the difficulties can be overcome by using, instead of lenses, mirrors that are curved. Telescopes using curved mirrors are called *reflecting telescopes.*

In order to understand how a reflecting telescope operates, let's try a few activities.

COMPARE

Examine carefully the flashlights that you and the other students in your classroom have been using. Some of them will be focusing flashlights. In a darkened room, using smoke or chalk dust, compare the different beams of light waves which can be given off by a focusing flashlight with the light beam produced by an ordinary flashlight. What do you observe? What causes this to happen? Can you find out for yourself by examining the reflecting surfaces in back of the light bulb on each of the flashlights? □□

The reflectors in flashlights are similar to the reflecting mirrors in a reflecting telescope. They are both concave mirrors. You have worked

with convex and concave lenses. In optical instruments mirrors are used as well as lenses. The inside of a ball is shaped like a *concave mirror*. The outside surface of the ball is like a *convex mirror*. Have you ever laughed at the distorted images produced by the curved mirrors in an amusement park? Or have you ever seen yourself in a shiny Christmas ornament or the bowl of a shiny silver spoon? What kinds of mirrors would the spoon bowl and the ornament be?

The focal length of a concave mirror can be determined by a procedure similar to the one you followed for convex lenses.

OBSERVE

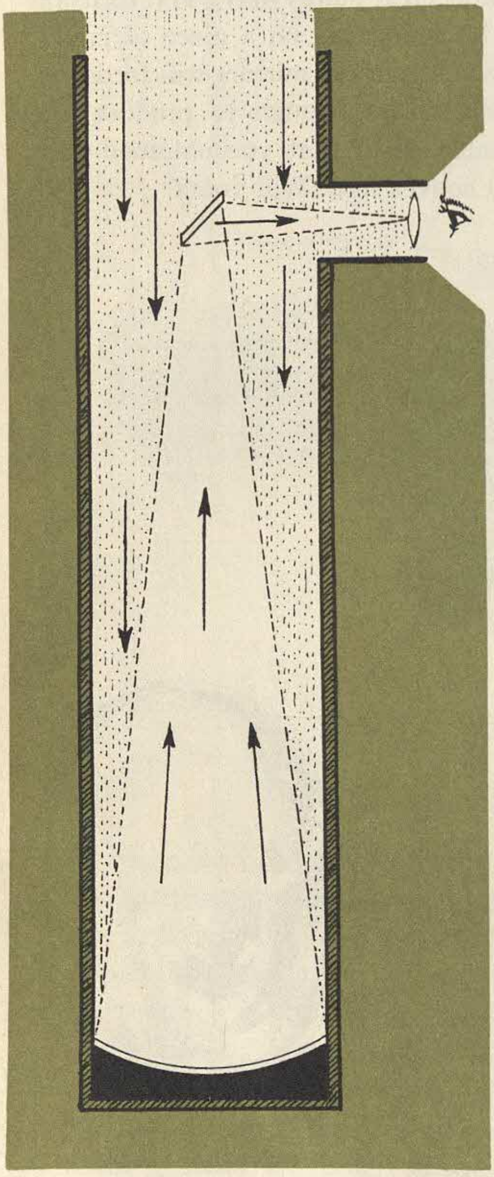
In a darkened room, shine two parallel narrow beams of light waves directly at a concave mirror. Two narrow parallel beams of light waves can be produced by cutting two thin parallel slits, about one inch apart, with a razor blade in the aluminum foil covering of your flashlight or projector. Of course your observations will be improved if the light beams travel through smoke or chalk dust in the air. What do you observe happening when the beams of light are reflected from the concave mirror? Can you determine the focal point of the mirror? Light a candle and put it at the focal point. What is the direction of the reflected rays?

COMPARE

Take your concave mirror outside on a sunny day. Try focusing the sun's rays on a piece of paper. Some concave mirrors will focus the sun's rays enough to produce the same effect that you obtained with a convex lens. Will yours?

MEASURE

Check your focal length determination by focusing the image of a distant object on a screen or folded piece of white construction paper. How does this measurement compare with your earlier measurement of focal length?

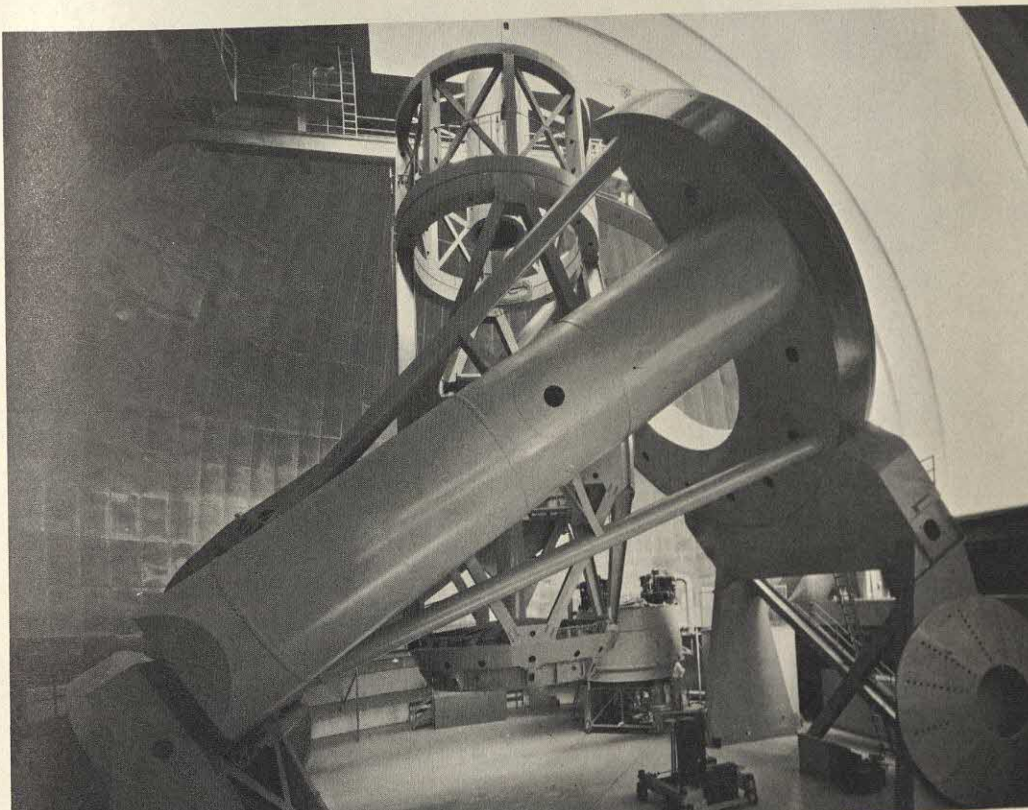


A diagram of a reflecting telescope is shown on this page. Where do you think the small flat mirror has been placed? You could make your own reflecting telescope, if you wanted to. What could you use for a tube? How long should the focal length of the mirror be? If you can get all the parts you need, why not try it? □□

In the year 1908, a reflecting telescope with an objective mirror 60 inches in diameter was installed in an observatory on Mount Wilson in California. The success of this instrument led to the development of a telescope with a 100-inch reflector. This telescope was first used in 1917 and is also located in an observatory on Mount Wilson. Can you think of some reasons for locating astronomical observatories on the tops of mountains?

In 1928, an American astronomer, George Hale, wrote the following: "Starlight is falling on every square inch of the world's surface, and the best we can do at present is to gather up and concentrate the rays that strike an area 100 inches in diameter." It took nearly twenty years to construct, but finally, in 1947, the world's biggest telescope was dedicated at the Mount Palomar Observatory in Southern California. This reflecting telescope contained a 200-inch Pyrex glass mirror coated with a thin surface of aluminum. Why must the mirror have a curved surface?

Mount Palomar Observatory



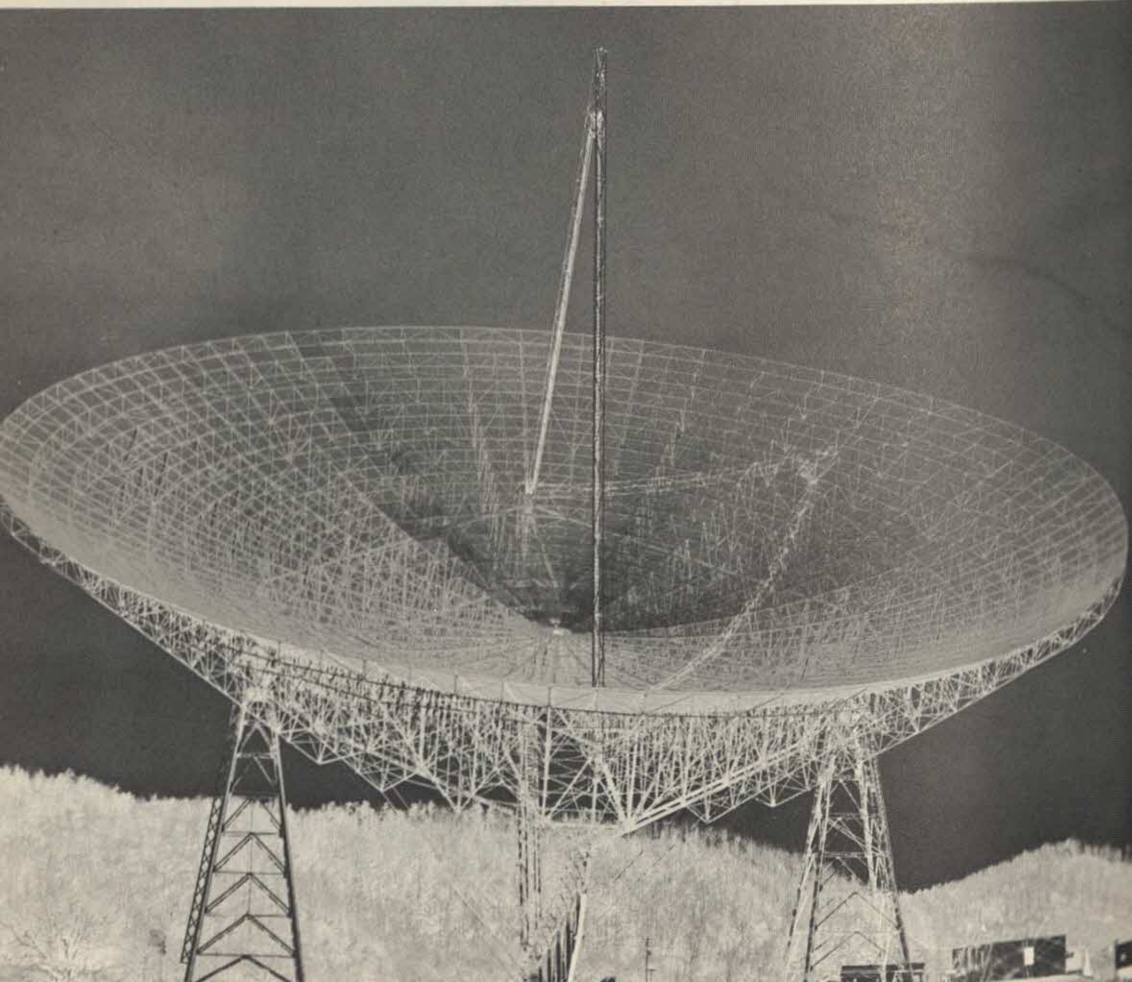
The 200 inch reflecting telescope inside the dome on Mount Palomar

In addition to optical telescopes, scientists make use of other instruments as they try to find out more about the universe in which we live. Radio telescopes which focus radio waves from outer space were first used in 1931. These instruments are used to study the radio waves given off by stars and galaxies. Radio telescopes can be much larger than even the largest reflecting telescope. In England, there is one with a reflector 250 feet in diameter. One such giant telescope is shown below.

Do you remember what happened when you allowed white light to pass through a prism and then observed and studied it? What you were doing was making an examination of the light waves. The scientific instrument known as the *spectroscope* analyzes light waves.

The spectroscope was developed in the early part of the nineteenth century by a German optician and physicist, Joseph von Fraunhofer (FROUN-hoh-fur), a Swedish physicist, A. J. Angstrom, and other sci-

This radio telescope in West Virginia has a diameter of 300 feet.



entists. This work was made possible by Sir Isaac Newton's earlier discoveries concerning the refraction of light by a prism. A spectroscope consists basically of three parts. The *collimator* allows only narrow bands of light waves from the source to strike the *prism*, where it is broken down for observation and study by viewing the spectrum through the *telescope*.

Try the following activity and see if you can discover how the spectroscope can be used to identify minute quantities of most elements.

ACTIVITY

For this activity you will need a bunsen burner, a propane burner, or an alcohol lamp. Take a piece of uninsulated copper wire and place it into the burner's flame. What do you observe? What color was the flame before you inserted the wire? What color is it while the copper wire is in it? Make concentrated water solutions of salts of each of the following substances: sodium, potassium, lithium, copper, barium, strontium, and calcium. Bend a four-inch piece

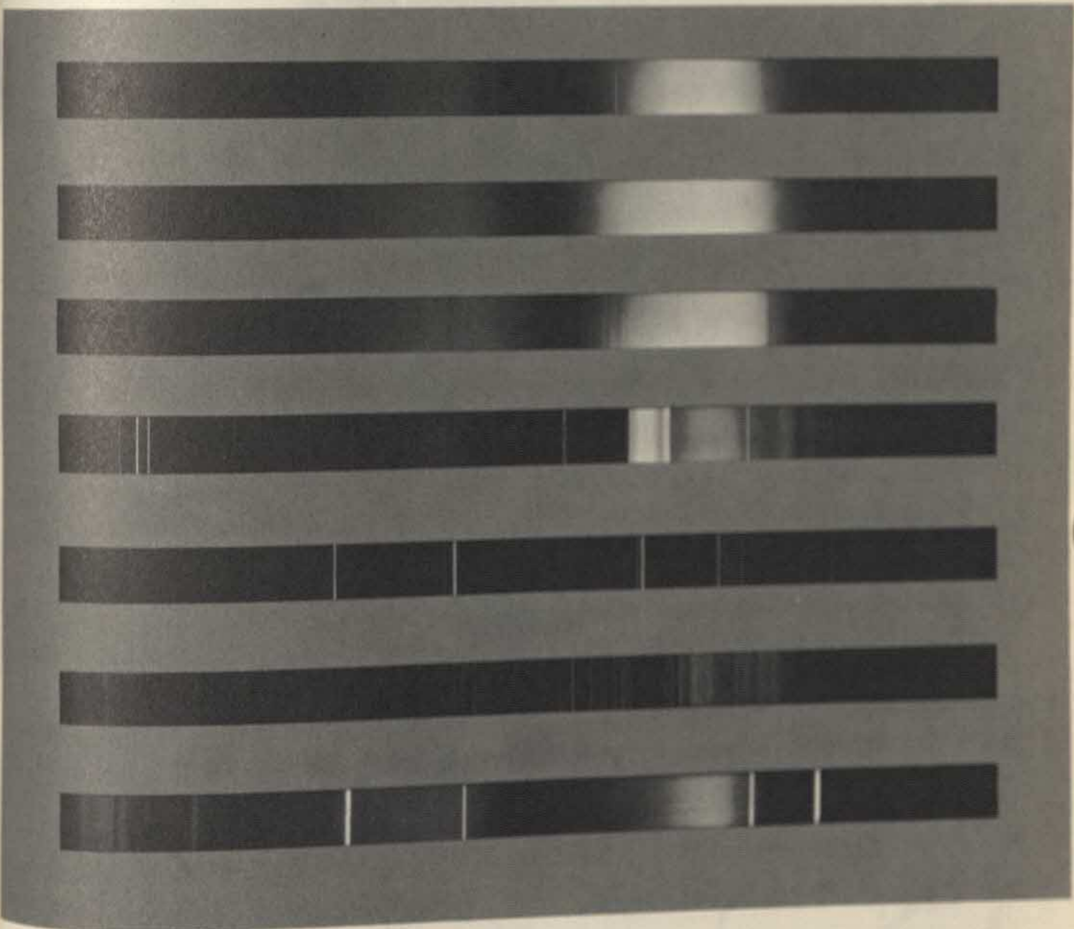
of platinum or nichrome wire into a tight loop and hold it with a pair of pliers. Place the wire loop in the flame. Do you notice any color change? Dip the wire into a concentrated solution of table salt (NaCl) and then place it in the flame. Do the same thing for each of the other solutions. Make sure that you either use a separate piece of wire for each solution or clean the wire thoroughly before you move from one solution to another. What did you observe about the color of the flame for each of the substances that you used?

With your eyes you are able to observe only the most dramatic colors given off by substances when they are heated. What looks like one color to the human eye is shown to consist of several distinct colors by the spectroscope. Earlier in this unit, you should have been able to observe some of the colors of the visible spectrum. By using a spectroscope, scientists can observe a great deal more.

The color patterns that you see on this page are photographs taken of various types of spectra. Each element produces its own characteristic spectrum (colors) when it is heated to a point where it gives off its own light. No two elements in the world produce exactly the same colors. □□

In the year 1868, the element helium was identified by spectroscopic studies of the sun. It was not until 1895 that helium was discovered on the surface of the earth. Using the spectroscope, scientists analyze the light given off by the sun and other stars. From this scientists are able to tell what these objects are composed of, even though the nearest of them are many billions of miles away.

No two elements produce exactly the same color patterns when viewed through a spectroscope.



Photography and the Camera

In the section of this unit dealing with sunlight, you learned that light energy can cause certain chemical reactions to take place. Some interesting chemical reactions take place in photography which, of course, have a great deal to do with light. The following demonstration will provide you with some idea of the relationship between photography and light.

DEMONSTRATION

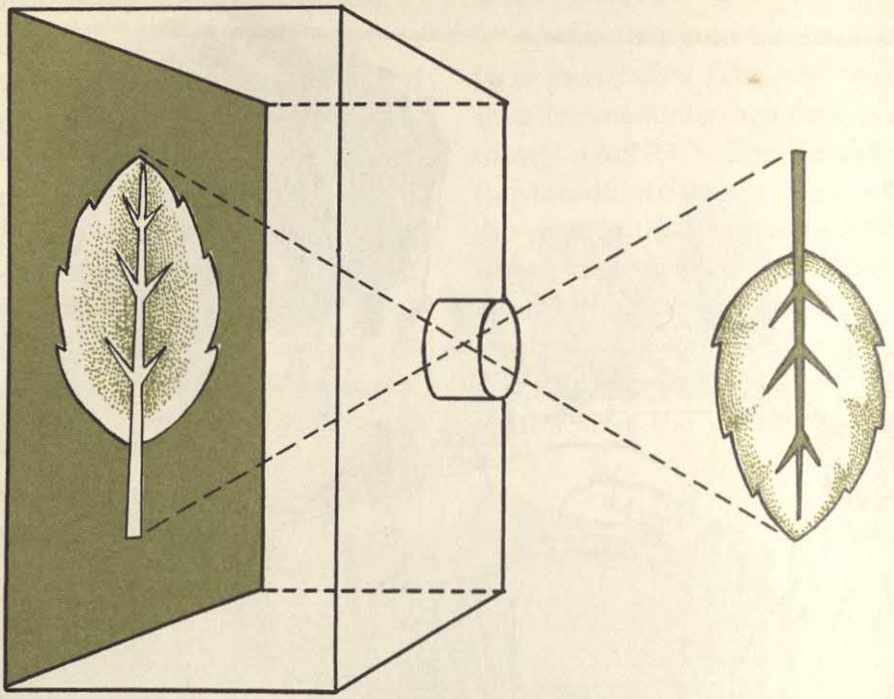
Notice that your teacher has two large test tubes. The first solution that he pours into each tube is silver nitrate ($AgNO_3$). The second solution is sodium chloride ($NaCl$). What did each of these solutions look like before they were mixed? What does the resulting mixture look like? Your teacher will cover each test tube. One of them will be placed in a desk drawer and the other one will be

passed around the room for your examination. When the test tube reaches you, record the colors you observe. After the test tube has been observed by everyone in class, how does it compare with the test tube kept in the drawer? What caused the change in the one that was passed around the room?

Perhaps you can explain what you observed. But before you do, try the following activity with the small piece of photographic paper that your teacher will give you. This is the paper that photographic prints (pictures) are made on.

COMPARE

Place the piece of photographic paper on your desk with its slick, shiny side facing up. Quickly place a coin, an eraser, or some other small solid object over part of this photographic paper. Look carefully at the part of the paper that you can still see. What do you observe happening? After about three minutes, remove the solid object from your paper. What do you observe when you compare the uncovered portion with the portion that was covered? What do you suppose caused the difference in the paper?



The following equation represents the chemical reaction which took place when the two solutions were mixed.

$AgNO_3$ +	$NaCl \longrightarrow$	$NaNO_3$ +	$AgCl$
Silver +	Sodium	Sodium +	Silver
Nitrate	Chloride	Nitrate	Chloride

In this chemical reaction, two new substances were formed–sodium nitrate (a clear liquid) and silver chloride (a white, curdy substance). The substance of particular interest for photography is the silver chloride. After exposure to light, you observed that this substance turned dark. The white silver chloride was changed by the energy of the light to black silver. Substances like silver chloride are termed *photosensitive substances.*

What kind of substances would you expect photographic films and papers to be coated with? Watch while your teacher holds up pieces of photographic film and paper. Which do you think is more sensitive to light? Why does a photographer have to work with most photographic films and papers in a darkroom?

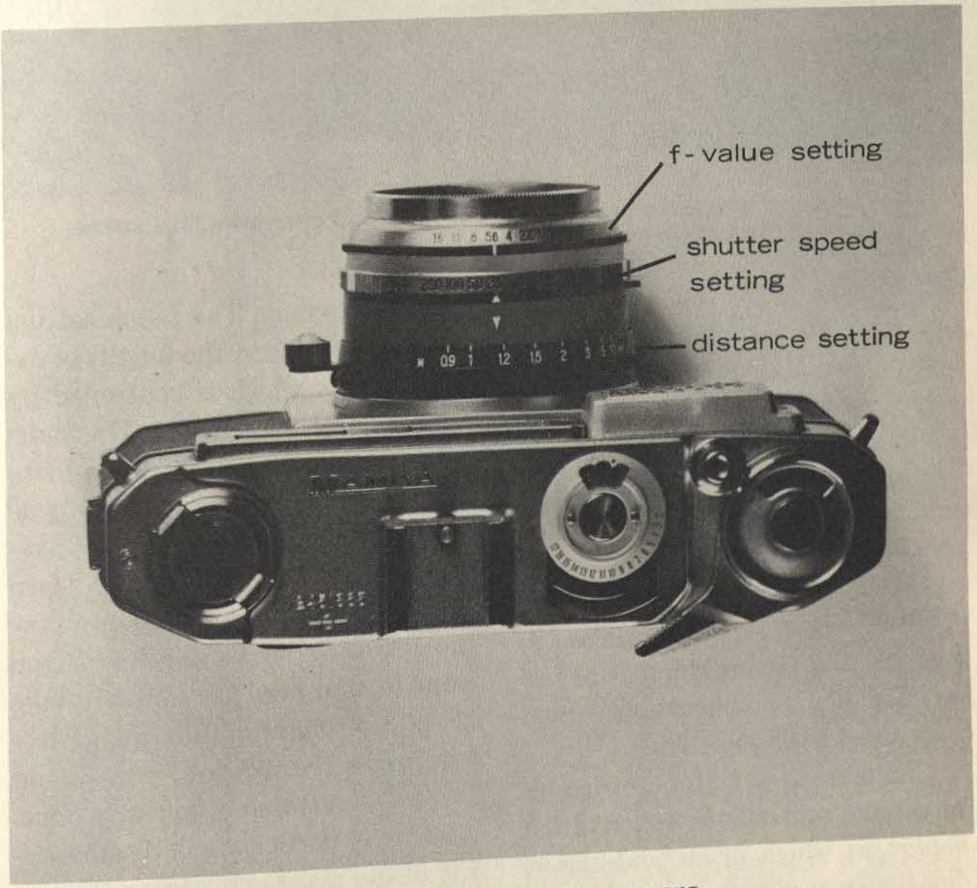
Many people do not know what happens between the time that the film is put into their camera and when they get to the camera shop to pick up their prints. Perhaps you do. But in any event, the following activities should be interesting for you.

ACTIVITY

We have already had some experience with cameras. Notice that all cameras consist of three basic parts—a lightproof box with a place to put the film, an opening through which light can pass, and a means for opening and closing the opening.

Cameras have developed considerably from this simplest form. What does your camera have instead of a pinhole opening? What did we use instead of a pinhole in the camera we made from the milk container? The picture shows a modern camera with the important parts labeled. If your camera is a box-type camera it will be much simpler than the one shown.

The *aperture* is the opening through which the light passes. The aperture, however, is always discussed in relation to the focal length of the camera's *lens*. This relationship is called the *f value*. It can be determined by dividing the focal length of the lens by the diameter of the lens opening. Fortunately, you



The parts of a modern camera

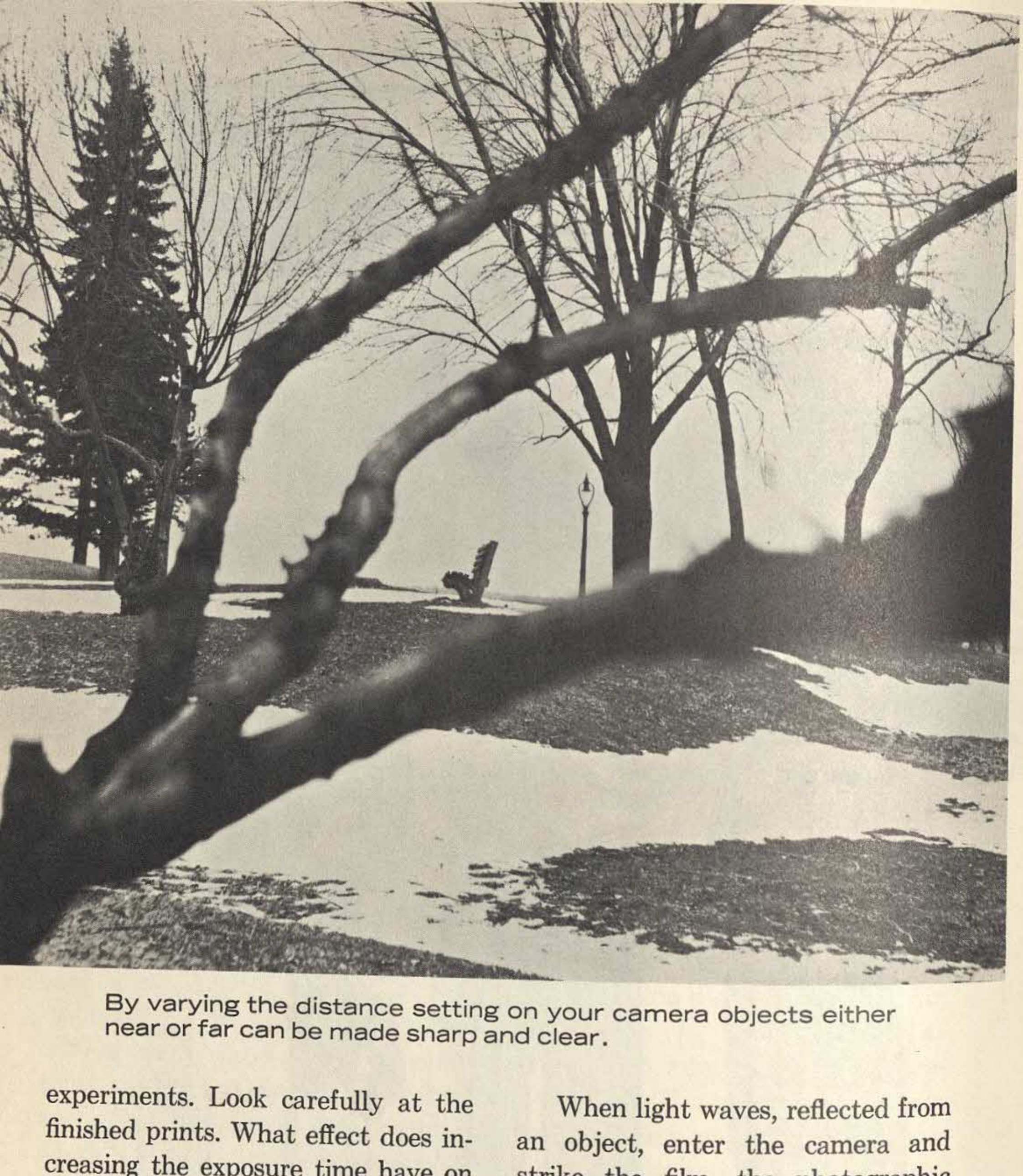
By varying the settings on your camera you can take the same picture different ways.

do not have to do this every time you want to take a picture. The camera manufacturer has already done this for you. The series of numbers ranging from f1.8 to f32 are the "settings" called f stops at which the camera may be used. Lighting conditions, the kind of film in the camera, and other factors will determine at which f stop to set your camera. A good practice for beginners is to follow carefully the instructions which come along with your film.

Changing the f stop setting of the camera controls the action of the *diaphragm* which opens and closes, allowing varying amounts of light to enter the camera. The f stop setting will also determine the length of exposure time, which is controlled by the action of the *shutter*. The shutter settings on the illustrated camera range from $\frac{1}{100}$ of a second to as long as you want the camera to remain open. To really begin to learn about cameras and photography, try the following activity. (Unless you want to, you need not actually take all of the pictures. But no matter who takes the pictures, you should try to understand what was done. Also try to participate in the answering of the questions, examination of prints, and discussion.)

EXPLORE

Take a series of pictures of 4 of your classmates or friends, standing at distances of 8, 15, 25 and 100 feet from you. Keep a record of your camera settings for each picture that you take. Take pictures with each of your classmates "in focus," but make sure that the 4 of them are in every picture that you take. Vary the f stops that you use, as well as the exposure times. When you take the roll of film to the photography shop ask the person in charge to print all of the pictures with the same settings on the enlarger. If this is not done, you will be unable to draw correct conclusions from your



By varying the distance setting on your camera objects either near or far can be made sharp and clear.

experiments. Look carefully at the finished prints. What effect does increasing the exposure time have on a print? What effect does changing the f stop have? At which set of camera settings (f value and shutter speed) do you observe the best overall print of all 4 students? What other conclusions can be drawn from your examination of the prints?

When light waves, reflected from an object, enter the camera and strike the film, the photographic process begins. If you were to open the camera at this point, do you think that you would see anything on the film? There is a *latent image* at this time, but it does not become visible until after the film has been chemically treated.

ACTIVITY

Examine some negatives. What is the most obvious thing that you notice about them? Imagine that you took a picture of a large black spot on a white background. What color would the spot be on the negative? What color would the background be? Which part of the subject reflects more light, the black spot or the white background? Can you explain why the negative appears the way it does? □□

We get very little satisfaction from looking at a negative. It is almost impossible to identify even our closest friends from a negative. What is needed is a positive print. And you will now learn how to make positive prints from your negatives.

What causes the light and dark areas in a negative?

INVESTIGATE

With your classmates form groups of 4 to 6. Each group should obtain the following materials. Obtain Tri-Chem Paks and photographic print paper. The other items can be brought from home by different members of the group.

Kodak Tri-Chem Pak
"Slow" photographic paper in a box or envelope

Newspapers

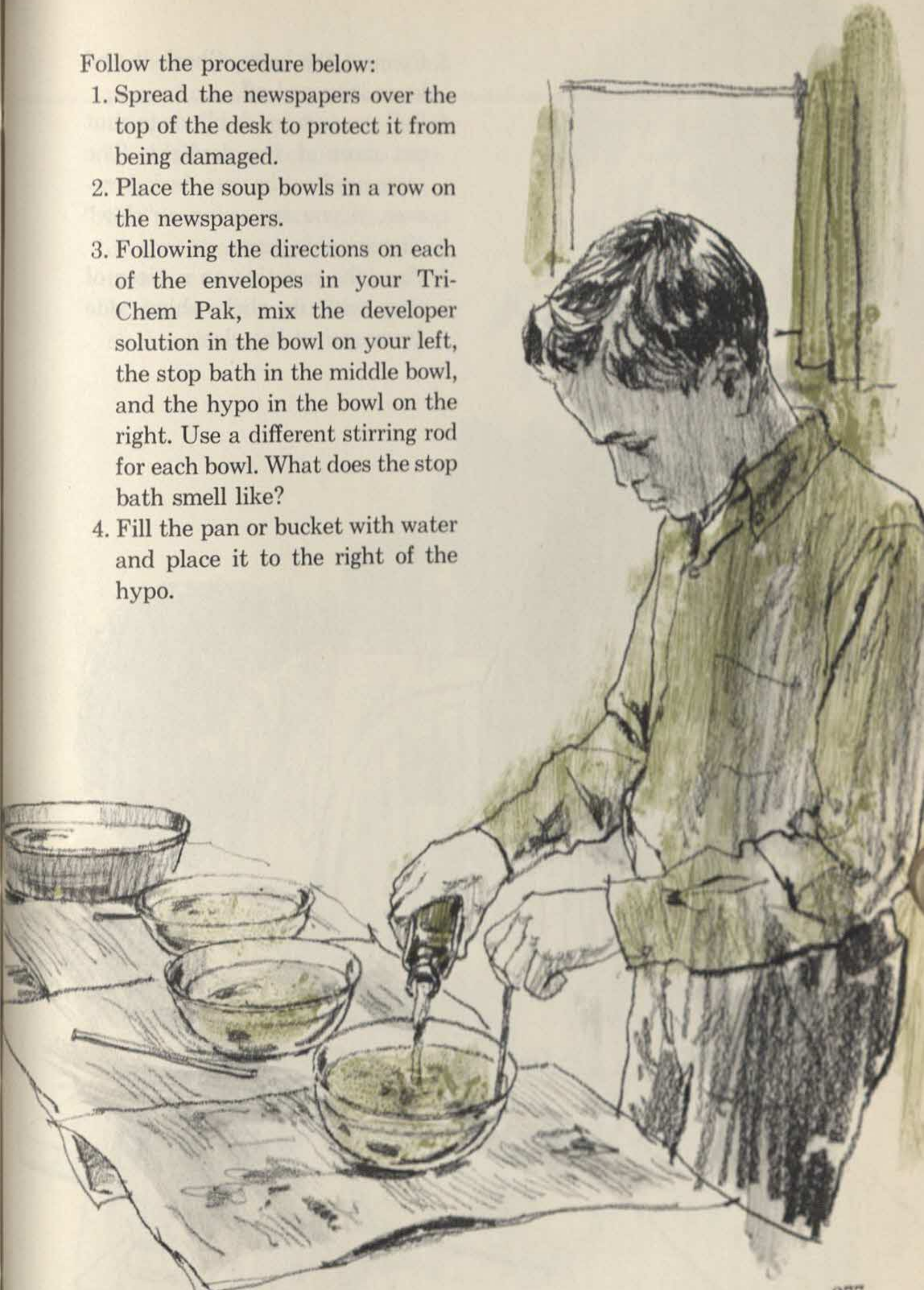
3–Wide soup bowls
1–Measuring cup
3–Stirring rods
2–Tweezers
2–Clear glass plates
2–Snap clothes pins
1–Lamp with 60-watt bulb
1–Dish pan or bucket
1–Cloth towel for each group member

Some photographic negatives

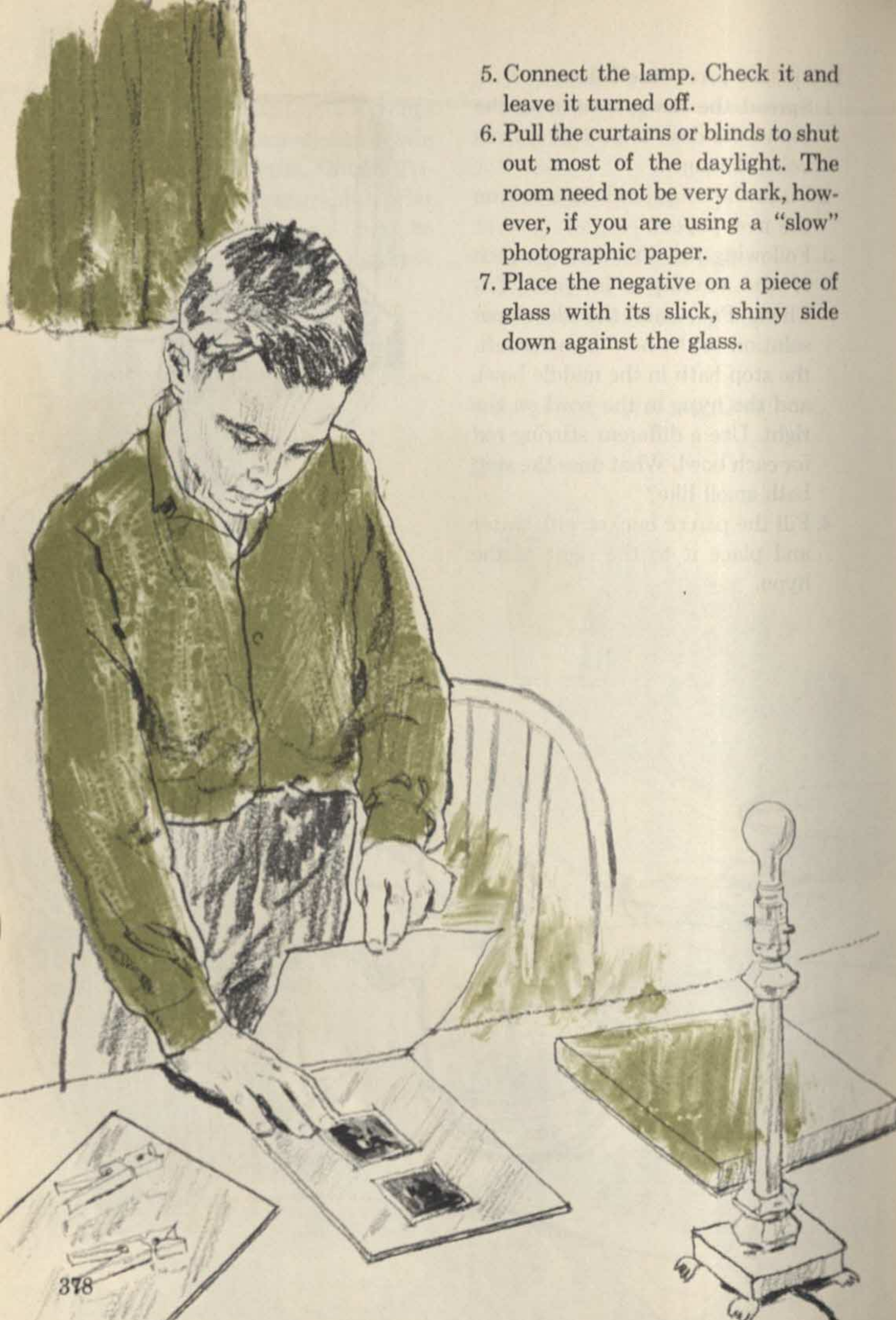
Paper towels

Follow the procedure below:

1. Spread the newspapers over the top of the desk to protect it from being damaged.
2. Place the soup bowls in a row on the newspapers.
3. Following the directions on each of the envelopes in your Tri-Chem Pak, mix the developer solution in the bowl on your left, the stop bath in the middle bowl, and the hypo in the bowl on the right. Use a different stirring rod for each bowl. What does the stop bath smell like?
4. Fill the pan or bucket with water and place it to the right of the hypo.



5. Connect the lamp. Check it and leave it turned off.
6. Pull the curtains or blinds to shut out most of the daylight. The room need not be very dark, however, if you are using a "slow" photographic paper.
7. Place the negative on a piece of glass with its slick, shiny side down against the glass.



8. Remove one piece of photographic paper from your paper box or envelope. Quickly place its slick, shiny side down against the negative.
9. Put the second glass plate on top of the film and clip everything together with the clothespins. Make sure that you don't get the clothespins over the negative.

10. Hold the arrangement about 18 inches away from the light bulb with the negative facing the bulb. Turn the bulb on for about 5 seconds. Then turn it off.
11. Place the piece of photographic paper in the developer solution. When the print is sufficiently clear and dark (about one minute), remove it with one of the tweezers and drop it into the stop bath.
12. After about 15 seconds, use the other pair of tweezers to remove the print from the stop bath and place it in the hypo. (You may have as many prints as you want in the hypo at the same time.)
13. After 10 to 15 minutes place the print in the wash pan or bucket, where it should remain for 12 to 24 hours with two or three water changes. As an alternative procedure, the prints may be washed in slowly running water for about an hour.

14. Remove the prints from the wash water and place them, side by side, between several thicknesses of paper toweling. Place books on top of the towels so that the prints will dry flat.
15. Make some other designs as well as photographic prints, by arranging leaves, flowers, keys, and other opaque objects on the photographic paper. Shine the light on them for about 30 seconds. And then develop the photograms as previously described.

Would you like to take up photography as a hobby?

Prints should become acceptable after about 50 to 60 seconds in the developer solution. If a print gets dark after about five seconds in the developer, what can you do to correct this situation? If a print does not get dark enough after about a minute in the developer, how can this be corrected?

Each time a photographic film is developed, a miracle takes place; a miracle involving light and chemical change, a miracle involving matter and energy. As the energy of light interacts with the light-sensitive atoms of the film, chemical changes take place in the atoms, recording for the future an instant in time. This event is stored in the film the moment light strikes it. When the hidden image in the film is made to come into view, another change takes place, another miracle. These mysteries involving light and atoms are no stranger than the mysteries of sound, with its rhythms, meaning, music, and noise. The miracles of sound and light are no greater than those involving waves. The brilliant concept of energy, which man has created to explain what he sees and hears, is another miracle. All of these miracles are certainly no greater than the miracle of you and the way you interpret the world around you.

THINK

1. If a tree were to fall in a forest with no one there to hear, would a sound be produced? Explain your answer.
2. Why is it impossible to see a rainbow in the same part of the sky as the sun?
3. How can you measure the depth of a lake using an instrument that can send out sound waves? What is sonar? What is radar?
4. Why are soldiers told to "break step" when they are marching across small bridges?
5. If light travels at about 186,000 miles per second and the sun is 93,000,000 miles away, how many minutes does it take light leaving the sun to reach Earth? If the sun were to suddenly explode, how much time would pass before we could see the explosion?

PROJECT

Make a ripple tank to study water waves. One way to make a ripple tank is to use a clear plastic box or a glass baking dish, some waxed paper, a flashlight, and a few books to hold up the baking dish.

1) Fill the box or dish with water.
2) Cut a small hole in the center of the waxed paper and wrap it around the dish.
3) Tap the water.
4) Using the picture on this page as a guide, arrange the books so that a lighted flashlight can be placed underneath.
5) Dim the lights in the room and tap the water through the hole with the point of a pencil.
6) Using a watch or a clock with a second hand, make and record your measurements of the water waves.
7) Think of as many ways of studying waves as you can with your ripple tank. Try your ideas. Record your results.
8) If your teacher selects you, report to the class.

GLOSSARY

accelerate (ak-SEL-uh-*rayt*). The change in an object's velocity divided by the time taken for the change.

aerobic (*a*-RHO-bik). Those bacteria that must have oxygen present for growth.

air-borne (AIR-BORNE). Spread of disease by microorganisms in the surrounding air.

air resistance (AIR rih-ZIS-tuns). Force that air exerts on objects pushing or rubbing against it.

ameba (uh-MEE-buh). Single-celled animal that has an irregular and constantly changing shape.

ammonia (uh-MOHN-yuh). Gas composed of nitrogen and hydrogen; formula is NH_3.

amplitude (AM-pluh-*tood*). Distance the particles in a wave move from normal position of rest, or the amount of energy carried by the wave.

anaerobic (*an*-uh-ROH-bik). Those bacteria that are able to grow without the presence of oxygen.

anatomy (uh-NAT-uh-mih). The physical structure of plants and animals.

anesthetic (*an*-uhs-THET-ik). A gas or drug which reduces the sensitivity of the nervous system.

angle of incidence (ANG-gul OV IN-sud-unts). Angle at which light strikes a mirror or lens.

angle of reflection (ANG-gul OV ri-FLEK-shun). Angle at which light rays are reflected from a mirror.

Anopheles mosquito (uh-NAHF-uh-*leez* muh-SKEE-toh). Insect that transmits the protozoan that causes malaria.

anthrax (AN-*thraks*). Infectious disease of cattle and sheep caused by spore-forming bacteria.

antiseptic (*an*-tuh-SEP-tik). Solution such as iodine or alcohol that kills disease-causing germs.

aperture (AP-uhr-chur). Small opening through which light can pass.

Argentum (ahr-JEN-tum). Latin name for silver from which we get its symbol, Ag.

Aristotle (*ar*-uh-stuh-TUHL). Greek philosopher who agreed with the ancient theory that all things on earth were composed of four "elements".

artery (AHR-tuh-rih). Tube carrying blood from the heart to other parts of the body.

aseptic (ay-SEP-tik). Free from organisms that cause infection or disease.

athlete's foot (ATH-*leets* FOOT). Fungus infection caused by a ringworm.

atom (AT-uhm). The smallest particle of an element that has all the properties of that element.

atomic energy (uh-TAHM-ik EN-

To aid in pronunciation all primary stress syllables have been put in capital letters and the secondary stress syllables are in italics.

uhr-jee). The force and power obtained from the splitting of an atom.

atomic model (uh-TAHM-ik MAHD-uhl). Form of the atom as scientists visualize its complete structure.

atomic number (uh-TAHM-ik NUM-bur). The number of positively charged particles in the nucleus of an atom.

Aurum (OHR-um). Latin name for gold which has the symbol Au.

autoclave (OT-oh-*klayv*). Device using superheated steam under pressure to kill disease-producing organisms.

average speed (AV-uhr-ihj SPEED). Overall rate an object travels through a specific distance.

bacillus (buh-SIL-uhs). Rod-shaped form of certain bacterial organisms.

bacteria (bak-TIHR-ih-uh). Tiny, one-celled plants; some cause disease and others are useful to man.

bearing (BAIR-ing). Circle of metal allowing a turning part to move with less friction.

bloodletting (BLUD-*let*-ing). Release of blood from the body which doctors once thought relieved pain and pressure.

boric acid (BOHR-ik AS-id). Mild antiseptic, often used to bathe eyes.

botanist (BAHT-un-uhst). Individual trained in the scientific study of plants.

breeding place (BREE-ding PLAYS). Area favorable for the growth and reproduction of disease-carrying insects.

Brownian motion (BRAU-ne-uhn MOH-shun). Zig-zag movements performed by microscopic particles in liquids or gases.

budding (BUD-ding). Process by which yeast plants reproduce themselves.

carbolic acid (KAHR-*bahl*-ik AS-id). Disinfectant solution used in water as an antiseptic.

carbon tetrachloride (KAHR-buhn te-truh-KLOHR-*eyed*). Colorless liquid used as a solvent and fire extinguisher.

carrier (KAR-ih-uhr). Person or animal which transmits disease but does not get the disease.

case history (KAYS HIHS-tuh-rih). Medical record of an individual prepared by a doctor.

cell (SEL). Smallest living unit of a plant or animal.

cesspool (SES-*pool*). An underground catch basin for household sewage or other liquid waste.

chain reaction (CHAYN ree-AK-shun). Process in which neutrons from split atoms go on to split more atoms, releasing energy in the process.

chemical formula (KEM-i-kuhl FOR-myuh-luh). Use of symbols to show the elements making up a compound.

chemical symbols (KEM-i-kuhl SIM-buhlz). Letters used by scientists as a convenient shorthand for the names of elements.

chicken pox (CHIK-un POKS). Mild contagious disease, causing red spots on the skin.

chlorine (KLOHR-een). Chemical element used in bleaches and purification of water.

chlorophyll (KLAWR-uh-fihl). The green material in plants necessary for the manufacture of food.

cholera (KAHL-uhr-uh). Severe infectious disease causing vomiting, diarrhea, weakness, and muscular cramps.

cloud chamber (KLAUD CHAYM-buhr). Device used to study the tracks of atomic particles.

coarse adjustment (KAWRS uh-JUST-munt). Knob on a microscope used for first getting image in focus under low power.

coccus (KAHK-uhs). Spherical shape of bacteria.

collide (kuh-LEYED). When objects meet and strike together with great force.

collimator (KAHL-uh-*mayt*-uhr). Device for producing a beam of parallel light rays.

colony (KOL-uh-ni). Large group of microorganisms growing on a culture medium.

communicable (kuh-MYOO-nuh-kuh-bul). Those diseases that are transmitted easily from one person to another without actual contact.

compound (kahm-PAUND). Substance consisting of two or more elements in a chemical combination.

compound microscope (KOM-pound MY-kruh-*skohp*). Instrument that magnifies by using a series of different sized lenses.

compression (kom-PRESH-un). The part of a longitudinal wave in which the vibrating particles are closest.

concave (KON-kayv). Type of lens that is thinner at the center than the edges; spreads apart light rays.

conclusion (kun-KLOO-zhun). The result of scientific reasoning after all known facts are considered.

contamination (kun-*tam*-uh-NAY-shun). Spreading infection by contact with microorganisms.

contraction (kun-TRAK-shun). A drawing together, shrinking or shortening; the space between molecules lessens.

control (kun-TROHL). The part of an experiment not including the condition being studied; this is a check for comparing results.

converge (kon-VURJ). To come together at a particular point.

convex (kon-VEKS). Type of lens which is thicker at the center than the edges; causes light rays to come together.

copper sulfate (KAHP-uhr SUHL-*fayt*). Compound consisting of the elements copper, sulfur, and oxygen that forms blue-green crystals.

corpuscular theory (kor-PUS-kyu-luhr THEE-ur-ri). Scientific concept that light rays are made up of individual particles.

cowpox (KOU-*poks*). Contagious disease of cows; cowpox organisms are used for smallpox vaccination.

crest (KREST). The top or peak of

any water or sound wave.

crystal (KRIST-ul). Solid object with flat sides, formed naturally from a liquid or material dissolved in a liquid.

culture (KUL-chur). Growth of bacteria under set conditions of heat, light, and moisture.

culture medium (KUL-chur MEE-di-um). Nutrient mixture used for growing bacteria, molds, and other fungi.

cycle (SY-kul). The complete course of a wave motion.

data (DAY-tuh). Gathered information; facts and figures.

decelerate (dee-SEL-uh-*rayt*). Slowing down the rate of speed.

Democritus (deh-MAHK-rih-tus). Greek philosopher who suggested that substances were made of tiny particles that could not be made smaller.

deuterium (dyoo-TIR-ee-uhm). Form of hydrogen called heavy hydrogen, consisting of one proton, one electron, and one neutron.

diabetes (*di*-uh-BEE-tis). Condition resulting from the body being unable to absorb a normal amount of sugar.

diagonal (dy-AG-uh-nul). Slanting straight line between any two corners not next to each other in a figure of four or more sides.

diaphragm (DY-a-*fram*). A thin, movable shutter to adjust the intensity of light entering a camera.

diarrhea (*di*-uh-REE-uh). Frequent and watery bowel movements.

diffused reflection (di-FYOOZED ri-FLEK-shun). The scattering of light rays as they are reflected from any surface.

diphtheria (dif-THIR-ih-uh). Severe and communicable disease affecting the throat.

direction (dih-REK-shun). Point toward which an object faces or moves.

disease (di-ZEEZ). Any condition interfering with the normal functioning of the body.

dissolve (diz-AHLV). To mix evenly through a fluid so that the particles are no longer visible.

dissect (dih-SEKT). The cutting into pieces of a plant or animal to study inner structure.

distance meter (DIS-tuns MEE-tur). Device to show how far an object has traveled.

diverge (di-VURJ). Spreading apart of light rays.

Doppler effect (DAHP-luhr ih-FEKT). Change in frequency of a wave due to the motion of the wave source.

droplet (DRAHP-lut). Small amount of liquid.

dysentery ameba (DIS-en-ter-*ee* uh-MEE-buh). Single-celled organism that causes severe diarrhea.

echo (EK-oh). Repetition of sound caused by the throwing back of sound waves.

electron (i-LEK-*trahn*). Tiny particle of matter having one unit of negative charge.

electron microscope (i-LEK-*trahn* MY-kruh-*skohp*). Instrument in which a beam of electrons is used to magnify organisms too small to be seen with an ordinary microscope.

element (EL-uh-munt). Simplest form of matter that cannot be broken down into other substances by ordinary methods.

energy (EN-uhr-ji). The capacity to do work; that which produces change in matter.

Empedocles (em-PED-oh-klees). Greek who taught that all substances were made of earth, air, fire, and water.

enlarger (en-LAHRJ-ur). Photographic device which can increase the size of a picture.

environment (en-VY-run-munt). All factors, both living and nonliving, making up the surroundings of an organism.

epidemic (*ep*-uh-DEM-ik). General attack of a disease in a particular area; spreads from person to person.

Epsom salt (EP-suhm SOHLT). White crystals made from magnesium, sulfur, and oxygen.

ethyl alcohol (ETH-uhl AL-kuh-*hol*). Colorless liquid formed from the fermentation of sugars.

evaporate (i-VAP-uh-*rayt*). Change from a liquid to a gas by the absorption of heat.

expansion (ik-SPAN-chun). Spreading apart of molecules when heat is applied to an object.

external force (eks-TUR-nul FAWRS). An outside condition which can change how fast an object is moving and its direction.

eyepiece (EYE-*pees*). The microscope lens nearest the eye of the user.

farsighted (FAHR-*syt*-id). Able to see distant objects; light rays do not focus sharply on the retina.

fermentation (*fur*-men-TAY-shun). Chemical change brought about by yeasts and certain bacteria.

Ferrum (FER-um). Latin name for iron, from which we get its symbol Fe.

fertilizer (FUR-tuh-*ly*-zur). Material used to make soil more productive.

field (FEELD). The circular area seen when looking into a microscope.

filter (FIL-tur). Porous material used as a strainer for tiny particles in a solution.

final velocity (FY-nul vuh-LOS-uh-tih). The last speed an object reaches before it stops moving.

fine adjustment (FIHN uh-JUST-munt). Microscope knob used to focus objects viewed under the high power lens.

flame test (FLAYM TEST). Identification of elements by the color they give when placed in a flame.

focal length (FOH-kul LENGKTH). Distance from a mirror or lens to its principal focus.

focal point (FOH-kul POINT). The point at which light rays come together.

focus (FOH-kus). The point at which light rays passing through

any lens converge or diverge.

force (FAWRS). An action which affects the state of motion or rest in matter; a push or pull.

fossil (FAHS-uhl). Remains of ancient animals and plants buried in the earth or imbedded in rock.

frequency (FREE-kwun-si). The number of wave vibrations per second.

friction (FRIK-shun). Resistant force making it difficult to roll or slide objects over each other.

gas (GAS). State of matter having no definite shape and no definite volume.

germ (JURM). Tiny animal or plant that may cause disease.

graphite (GRAF-*yt*). Black, soft form of carbon used in the making of pencils.

gravitation (*grav*-uh-TAY-shun). Mutual force of attraction existing between all bodies in the universe.

heal (HEEL). To bring back to good health.

helium (HEE-lee-uhm). Light, colorless gas used in weather balloons.

horizontal (*hor*-uh-ZON-tul). Direction parallel to the line where earth and sky meet.

horsepower (HAWRS-*pou*-uhr). Unit of power equal to 550 ft-lb/second.

hydrogen peroxide (HY-druh-jun puh-RAHK-*syd*). Compound of hydrogen and oxygen used as a disinfectant to kill bacteria.

hypo (HY-poh). Solution used to develop photographs; it stops the action of the developing solution and fixes the photograph.

ideal conditions (i-DEE-uhl kun-DISH-unz). State in which resistance to forward motion is at a minimum.

image (IM-ij). Object seen by reflection of light from a smooth, polished surface, or by refraction of light through a lens.

immunization (*im*-yu-nuh-ZAY-shun). Protection from disease by vaccination or inoculation.

inertia (in-UR-shuh). Property of matter requiring that a force act on it in order to begin or change its motion.

infection (in-FEK-shun). A causing of disease by contact with microorganisms.

influenza (*in*-floo-EN-zuh). Severe, contagious, virus-caused disease affecting the respiratory system.

infrasonic (*in*-fruh-SAHN-ik). Sound with a frequency below the range of human hearing; below 20 cycles/second.

initial velocity (ih-NISH-ul vuh-LOS-uh-tih). The beginning speed at which an object moves.

inject (in-JEKT). Force a liquid into the body with a syringe and needle.

inoculation (ih-*nok*-yoo-LAY-shun). Voluntary addition of germs or viruses to a culture medium or living organism.

ion (EYE-uhn). Atom or group of

atoms having an electric charge caused by the gain or loss of electrons.

isolate (EYE-suh-*layt*). Set apart to prevent the spread of a contagious disease.

isotopes (EYE-suh-*tohps*). Atoms of the same element, differing in mass because they have different numbers of neutrons.

kaleidoscope (kuh-LY-duh-*skop*). Tube containing mirrors and colored glass that forms geometric patterns as it is turned.

knot (NOT). One nautical mile per hour; 6,076 ft/hr.

lens (LENZ). Polished, transparent substance with at least one surface curved and not parallel to the other.

like charge (LYK CHAHRJ). Electrical charges which are the same.

linear motion (LIN-ee-uhr MOH-shun). Movement in one direction, usually along a straight line.

liquid (LIK-wuhd). State of matter having a definite volume, but no definite shape.

longitudinal wave (*lon*-juh-TOO-di-nul WAYV). Wave in which the particles of the medium vibrate to and fro along the path which the wave travels through the medium.

lubricant (LOO-bruh-kant). Substance such as oil or grease that reduces surface friction.

luminous (LOO-muh-nus). Object which gives off light rays.

maggot (MAG-uht). Worm-like stage in the life of some insects between the egg and full-grown insect.

magnification (*mag*-nuh-fuh-KAY-shun). Making an object appear larger by using lenses.

magnifying power (MAG-nuh-*fi*-ing POU-uhr). Number which stands for the amount a lens or series of lenses is able to enlarge an object.

malaria (muh-LAIR-ih-uh). Disease causing chills, fever, and weakness; carried by Anopheles mosquito.

mass (MAS). A measure of the amount of matter.

matter (MAT-uhr). All substances in the universe having weight and volume.

maximum (MAK-suh-mum) **speed**. Highest rate of motion an object attains traveling over a specific distance.

measles (MEE-zulz). Contagious disease transmitted by a virus.

medium (MEE-di-um). The material that carries a wave.

methane (METH-*ayn*). Colorless gas formed from the breakdown of organic matter.

metronome (MET-ruh-*nom*). Device that beats time in loud ticks.

microbiology (*my*-kroh-by-AHL-uh-jee). Branch of biology concentrating on the study of microscopic forms of life.

microorganism (MY-*kroh*-OHR-guh-*niz*-um). A living organism of microscopic size.

microscope (MY-kruh-*skohp*). Instrument which uses an arrange-

ment of lenses to make tiny organisms large enough to be seen.

mold (MOHLD). Fungus growth appearing on the surface of decaying foods.

molecule (MAHL-i-*kyool*). Smallest part of an element or compound still having all the properties of the substance.

momentum (moh-MEN-tum). The product that results from an object's mass multiplied by its velocity.

motion (MOH-shun). A continuing change of the place or position of an object.

mumps (MUMPS). Contagious disease causing the jaw glands to swell.

natural element (NACH-uh-rul EL-uh-munt). Those that are present on the earth in a pure or combined form.

nautical mile (NAW-tuh-kul MYL). Distance of 6,076 feet.

nearsighted (NIR-*sy*-tid). Able to see clearly at close distance only; light rays focus in front of the retina instead of on it.

negative acceleration (NEG-uh-tiv ak-SEL-uh-*ray*-shun). Loss of speed because of increased forces of resistance.

negative charge (NEG-uh-tiv CHAHRJ). Condition of having more electrons than protons.

negative ion (NEG-uh-tiv EYE-uhn). Atom or group of atoms that has gained electrons.

neutral (NOO-trul). Containing a balanced number of positive and negative charges.

neutron (NOO-trahn). Atomic particle in the nucleus of an atom which does not carry an electric charge.

nucleus (NOO-kli-uhs). Central part of an atom which is composed of neutrons and protons.

objective lens (ub-JEK-tiv LENZ). The lens of a microscope nearest the object being examined.

opaque (oh-PAYK). Material that does not permit light to pass through it.

orbit (AWR-bit). The path that electrons travel around the nucleus of an atom.

organism (AWR-guh-*niz*-um). A living plant or animal.

parallel (PAR-uh-*lel*) **rays**. Those rays which are equally distant from each other as they travel from the light source.

paramecium (*par*-uh-MEE-shee-uhm). Protozoan that moves by waving tiny hairs; shaped like a slipper.

parasite (PAR-uh-*syt*). Plant or animal living in or on another of a different species and taking nourishment from it.

particle (PAHR-tuh-kul). Minute amount of a substance.

pasteurize (PAS-chuh-*ryz*). Destruction of disease-causing organisms in liquid food by heating to about 154°F and then rapid cooling to 5°F or lower.

pendulum (PEN-juh-lum). Freely swinging weight used in studying motion and in measuring time.

penicillin (*pen*-uh-SIL-in). Germ-killing drug made from molds; it is used in treating many infectious diseases.

period (PIR-y-ud). Time for one complete cycle, vibration, or back and forth motion.

periodic motion (pir-i-OD-ik MOH-shun). Movement of an object continually moving back and forth in a definite path in equal time intervals.

Petri dish (PEE-tree DISH). Small, shallow dish of thin glass with loose cover used for culturing bacteria.

photon (FOH-tahn). Single "packet" of light radiation.

photosensitive (foh-toh-SEN-sut-iv). Chemicals that react when exposed to light rays.

photosynthesis (*foh*-toh-SIN-thuh-sis). The changing of water and carbon dioxide into sugar in living plants, by the action of light in the presence of chlorophyll.

physical characteristic (FIZ-uh-kul *kar*-ik-tur-IS-tik). Specific property of an element such as color, odor, and weight.

pitch (PICH). Property of a sound that depends on the number of vibrations per second.

plague (PLAYG). Any dangerous disease that spreads quickly.

poliomyelitis (*poh*-lih-oh-*my*-uh-LY-tis). Contagious disease of the nervous system, sometimes causing paralysis.

pollution (puh-LOO-shun). Making unclean or impure by contamination with bacteria or harmful chemicals.

positive acceleration (POZ-uh-tiv ak-SEL-uh-*ray*-shun). Increase of an object's speed under the influence of one or more forces.

positive charge (POZ-uh-tiv CHAHRJ). Electrical condition of having more protons than electrons.

positive ion (POZ-uh-tiv EYE-uhn). Atom or group of atoms that has lost electrons.

postulates (PAHS-chu-luts). Rules proposed based on scientific reasoning.

potassium permanganate (puh-TAS-i-uhm PUR-man-guh-*nayt*). Purple crystals composed of manganese and potassium.

potential (puh-TEN-shul). The ability to increase or develop further.

potential energy (puh-TEN-shul EN-uhr-ji). Stored energy of matter because of its condition or position.

power (POU-uhr). Measure of the amount of work able to be done in a set amount of time.

prediction (pri-DIK-shun). A forecast based on known available data.

prescription (pri-SKRIP-shun). Written order by a doctor for the making and use of a medicine.

prism (PRIZ-uhm). Triangular lens that produces a spectrum of colors when white light passes through it.

property (PROP-ur-ti). Character-

istic of an element or compound.

proton (PROH-ton). Atomic particle in an atomic nucleus which has a positive charge.

protozoan (*proh*-toh-ZOH-un). Single-celled animal; all are microscopic and must live in water.

pus (PUHS). Yellowish-white substance produced by sores and abscesses.

push (POOSH). Exert force in a particular direction.

putrefaction (*pyoo*-truh-FAK-shun). Breaking down of substances by bacteria and fungi resulting in unpleasant-smelling products.

rabies (RAY-beez). Infectious disease of warm-blooded animals; can be given to man by the bite of an infected animal.

radioactive (*ray*-dih-oh-AK-tiv). Substance which gives off high-energy particles and rays.

radiometer (*rayd*-ee-AHM-ut-ur). Instrument for measuring the strength of radiant energy.

radio telescope (RAYD-ee-oh TEL-uh-*skop*). Device that picks up radio waves from heavenly bodies.

rarefaction (*rar*-uh-FAK-shun). The part of a longitudinal wave in which the vibrating particles are furthest apart.

ray (RAY). Beam of light, heat, or electrons.

reflected beam (ri-FLEKT-id BEEM). Light ray which is bounced back from any particular surface.

reflecting telescope (ri-FLEKT-ing TEL-uh-*skop*). Instrument using a large mirror to catch the light coming from distant objects.

refracting telescope (ri-FRAKT-ing TEL-uh-*skop*). Instrument using lenses to magnify the light coming from distant objects.

refraction (ri-FRAK-shun). Bending of light rays as they pass from one substance to another.

relative motion (REL-uh-tiv MO-shun). Comparison of an object's motion in relation to something else (frame of reference).

reproduce (*ree*-pruh-DOOS). Production of offspring in either animals or plants.

resonance (REZ-un-uns). Ability of anything to vibrate by absorbing energy of its own natural frequency.

retina (RET-uh-nuh). Tissue at the back of the eyeball which contains cells sensitive to light.

rickettsia (rik-ET-see-uh). Group of organisms midway between the viruses and bacteria in size, which cause disease.

ringworm (RING-*wurm*). Skin disease caused by various kinds of very tiny fungi.

Rochelle salt (ROH-*shel* SAWLT). Crystalline substance composed of potassium, sodium, carbon, hydrogen, and oxygen.

roller bearings (ROH-luhr BAIR-ings). Device used to reduce friction by the reduction of surface contact.

rotary motion (ROHT-uh-ree MO-shun). The movement of an object turning about an axis.

sanitary (SAN-uh-*ter*-i). Free from

dirt and disease-causing germs.

saprophyte (SAP-ruh-*fyt*). Type of plant which lives on non-living organic matter.

saturate (SACH-uh-*rayt*). To dissolve as much solute in a solution as possible.

sepsis (SEP-sus). Harmful condition resulting from the spread of bacteria or their products.

septic tan (SEP-tik TANK). Tank for sewage in which bacteria destroy the refuse and kill harmful germs.

shutter (SHUT-uhr). Part of a camera that covers the lens and is opened when a photograph is taken.

smallpox (SMAWL-poks). Contagious disease accompanied by fever and sores which often leave small scars on the skin.

sodium (SOH-dih-uhm). Element found in common table salt, giving off a yellow color in a flame test.

sodium sulfate (SOH-dih-uhm SUHL-*fayt*). Compound of sodium, sulfur, and oxygen.

solid (SAHL-id). State of matter having a definite shape and definite volume.

solute (SAHL-*yoot*). Any substance which dissolves in a specific liquid.

solution (suh-LOO-shun). Mixture of two substances in a liquid state; formed by dissolving a solute in a solvent.

solvent (SAHL-vunt). The liquid or gas in which a solute is dissolved.

spectroscope (SPEK-truh-*skohp*). Device using a prism or grating to separate light of different wavelengths; can be used to identify chemical elements.

spectrum (SPEK-trum). Band of colors formed when white light passes through a prism.

speed (SPEED). Rate at which an object is moving; distance an object moves divided by a set amount of time.

spirillum (spy-RIL-um). Bacterial shape generally long and curved or spiral in form.

spontaneous generation (spahn-TAY-nee-uhs *jen*-ur-RAY-shun). Incorrect theory that living things appear suddenly where no life existed before.

spore (SPAWR). Tiny cell produced by microscopic animals which can adapt to difficult growth conditions.

spring balance (SPRING BAL-uhns). Device for measuring weight that uses the stretching of a spring to indicate the heaviness of an object.

static electricity (STAT-ik ih-*lek*-TRIS-uh-tih). Building up of positive or negative charges on an object.

sterilize (STER-uh-*lyz*). Any process which gets rid of harmful bacteria.

stop watch (STAHP WOCH). Watch used to record times down to a fraction of a second.

symptom (SIMP-tum). Specific indication or sign of illness such as high fever or diarrhea.

tetanus (TET-uh-nus). Serious dis-

ease which may cause spasms of the jaw muscles; lockjaw.

translucent (trans-LOO-sunt). Able to transmit light, but not enough to see through clearly.

transmit (trans-MIHT). To cause or allow to pass along or through a particular medium.

transparent (trans-PAIR-unt). Able to transmit light so that you can see objects clearly through it.

transverse wave (trans-VURS WAYV). Wave in which the particles vibrate at right angles to the path along which the wave travels.

tritium (TRIT-ee-uhm). The heavy hydrogen isotope having two neutrons in each nucleus.

trough (TRAWF). The lowest point of a wave.

tsetse fly (SET-see FLI). Any of several kinds of African biting flies; one kind carries the germs of sleeping sickness.

tuberculosis (too-*bur*-kyoo-LOH-sis). Contagious disease caused by a bacillus-shaped organism which usually affects the lungs.

tuning fork (TOON-ing FAWRK). Metal two-prong fork which produces a sound of definite pitch when the prongs of the fork vibrate.

ultrasonic (*uhl*-truh-SON-ik). Sound with a frequency above the range of human hearing; above 20,000 vibrations per second.

uniform motion (YOO-nuh-*fawm* MO-shun). Movement that progresses evenly from start to finish.

unlike charge (un-LIK CHAHRJ). Electrical charges which are different.

vaccination (*vak*-suh-NAY-shun). The sore or scar caused by injecting vaccine.

vaccine (vak-SEEN). Killed or weakened germs of a disease, introduced into the body to make it resistant to attacks of that disease.

velocity (vuh-LOS-uh-tih). Speed of an object in a definite direction.

ventilate (VEN-tuh-*layt*). Bring fresh air into a room and get rid of the stale air.

vertical (VUR-tuh-kul). Up-and-down direction of any motion.

vibrate (VI-*brayt*). Move back and forth rapidly, sometimes producing a sound.

virus (VI-rus). The simplest form of living matter; mumps and measles are caused by viruses.

visible spectrum (VIZ-uh-bul SPEK-trum). Arrangement of seven colors which is found in a beam of white light.

water-borne (WAW-tur-BORNE). Spread of disease by microorganisms in the water supply.

watt (WOT). Unit of electrical power.

wave (WAYV). To move up or down or back and forth.

wavelength (WAYV-*lengkth*). Distance between any two corresponding points of a wave; from crest to crest or trough to trough.

wave theory (WAYV THEE-uh-ri). Concept that light travels in waves.

weight (WAYT). Measure of the pull of gravity on a body of matter.

weightless (WAYT-lus). The condition of matter when it is not being affected by gravity.

work (WURK). The product of the force necessary to move an object multiplied by the distance the object moves.

X ray (EKS RAY). Invisible rays of great penetrating power; produced when a stream of electrons strikes material object.

yeast (YEEST). Small plants used in fermentation processes.

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